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BSC	Design Calculation or Analysis Cover Sheet *Complete only applicable items.*	1. QA: QA 2. Page 1

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Normal Operation Airborne Release Calculation

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☐ Preliminary x Committed ☐ Final ☐ Cancelled

8. Notes/Comments

An LP-2.14Q-BSC review is not required because the results of this revised calculation have no impact on the use of the technical output by the end user, other organizations or disciplines.

Attachments	Total Number of Pages
See Section 9	14

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. Approved/Accepted (Print/Sign/Date)
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00C	Complete revision. Included requested ICRP-68 dose factors for dose calculations. Updated references and associated parameters. All pages are affected.	58	IV-5	Y Yuan [signature] 6/15/2005	J Wang [signature] 6/15/2005	DB Darling [signature] 6/15/05

The calculations contained in this document were developed by the Nuclear and Radiological Engineering and are intended solely for the use of Nuclear and Radiological Engineering in its work regarding Waste Handling System design. Yucca Mountain Project personnel from the Nuclear and Radiological Engineering should be consulted before use of the calculations for purposes other than those stated herein or for use by individuals other than authorized personnel in the Nuclear and Radiological Engineering.

CONTENTS

FIGURES

TABLES

ACRONYMS

ALARA	as low as is reasonably allowable
AMAD	activity median aerodynamic diameters
ARF	airborne release fraction
BWR	boiling water reactor
CEDE	committed effective dose equivalent
DCF	dose conversion factor
DDE	deep dose equivalent
DOE	U.S. Department of Energy
DTF	Dry Transfer Facility
ECRB	enhanced characterization of the repository block (drift)
FGR	Federal Guidance Report
FHF	Fuel Handling Facility
HEPA	high-efficiency particulate air filters
HVAC	heating, ventilation, and air-conditioning
ICRP	International Commission on Radiological Protection
LDE	lens dose equivalent
NRC	U.S. Nuclear Regulatory Commission
PWR	pressurized water reactor
RF	airborne respirable fraction
SDE	shallow or skin dose equivalent
SNF	spent nuclear fuel
TEDE	total effective dose equivalent
TODE	total organ dose equivalent

1. PURPOSE

The purpose of this document is to evaluate the potential dose consequences to the maximally exposed worker from airborne releases of radioactive materials under normal operations of the repository facilities. This evaluation is required to support the Preclosure Safety Analysis to ensure that the predicted doses are within the regulatory limits prescribed by the U.S. Nuclear Regulatory Commission (NRC).

2. QUALITY ASSURANCE

This document was prepared in accordance with LP-3.12Q-BSC, *Design Calculations and Analyses*. Because the results of this calculation are used to support Preclosure Safety Analysis relative to radiological safety of the repository, this document is subject to the requirements of *Quality Assurance Requirements and Description* (DOE 2004a, Section 2.2.2).

3. METHOD

Nuclear waste designated for permanent disposal includes commercial spent nuclear fuel (SNF), U.S. Department of Energy (DOE) SNF, and DOE and commercial high-level radioactive waste. Waste received at the repository is in the form of solid material. The casks are opened and the waste materials are transferred into waste packages for disposal. Nuclear fuel assemblies used in weapons-program reactors, nuclear-powered naval reactors, and research reactors, along with vitrified high-level radioactive waste, already are contained in sealed canisters when they arrive at the repository. The process of transferring canistered waste is not expected to create any scenario for release of radionuclides during normal operation.

If the repository receives only undamaged commercial SNF elements, the radioactive materials to be released under normal operating conditions would be radioactive contamination suspended from the external surfaces of the casks and canisters and the crud suspended from the surfaces of spent-fuel assemblies. However, it is more conservative to assume that some fuel elements will be damaged at the reactor or during transportation and handling operations. The high-efficiency particulate air filters (HEPA) of the waste transfer facility ventilation system would remove most of potential airborne contamination and there would be little, if any, radioactive effluent from the repository. Radioactive gases are not released after the SNF is packaged into the leak proof waste package or storage cask and emplaced in the subsurface emplacement drifts or temporarily stored at the on-site aging pads.

The repository aging casks are designed to maintain structural integrity during normal and off-normal storage conditions. The casks are loaded, sealed, and decontaminated prior to transfer to the aging pads. The casks are sealed airtight with a helium atmosphere to preclude oxidation of the fuel. After loading, casks are leak tested in accordance with *American National Standard for Radioactive Materials — Leakage Tests on Packages for Shipment* (ANSI N14.5-97).

3.1 SURFACE FACILITIES

Surface facilities are designed to receive waste shipments and to unload, handle, and package waste into waste packages for underground emplacement. Events that might release radioactive material to the atmosphere include cask venting, fuel failures during handling operations and temporary storage, and resuspension of cask surface contamination during temporary storage. Among the surface facilities that have potential to release radioactive materials to the environment during normal operation are Fuel Handling Facility (FHF), Dry Transfer Facility 1 (DTF1), Dry Transfer Facility 2 (DTF2) and Aging Facilities. The Canister Handling Facility, as described in *Canister Handling Facility Description Document* (BSC 2005f, Section 1.1), is designed to handle only sealed canisters, and therefore it is not expected to release any airborne radioactive materials under normal operating conditions. The SNF Aging facilities are designed to provide space for aging commercial SNF from nuclear plants and for staging defense SNF and High-Level Waste from DOE. The potential release consequences from normal operation of Aging facilities can be found in *Aging Facility Worker Dose Assessment* (BSC 2005b) and therefore aging related releases are not repeated in this calculation.

A set of potential abnormal events was identified as part of normal operations in *Categorization of Event Sequences for License Application* (BSC 2005e, Section 7.4). These potential abnormal events as described are not expected to result in additional releases other than those estimated in Table 9 of this document. It is because the potential source terms from these releases, if any, would be originated from the damaged fuel assemblies that are already accounted for in estimating the total releases (Table 9). Abnormal events, such as failure of a seal or leak during normal or off-normal operations would not result in loss of area confinement or release of radioactive contamination to worker occupied areas, because air would continue to flow into the primary confinement ventilation systems and exhaust through the heating, ventilation, and air-conditioning (HVAC) stacks.

3.1.1 Normal Release Rate

The airborne normal release rate is the amount of radioactive material, in curies, released to the air per year under normal operating conditions at the repository. The airborne respirable normal release rate, Rr, is calculated as (DOE 1994, p. 1-2):

Airborne Respirable Normal Release Rate (Ci/yr), Rr = Q F ARF RF LPF (Eq. 1A)

where

Q = SNF process rate (Ci/yr)

F = Failed fraction of SNF processed

ARF = Airborne Release Fraction–The fraction of processed SNF that is suspended or released from the fuel assemblies

RF = Airborne Respirable Fraction –Fraction of airborne radioactive particles that is in the respirable size range

LPF = Leakpath Factor–The leakpath factor is the fraction of airborne released material that escapes to the atmosphere from the heating, ventilation, and air-conditioning confinement systems.

With the assumption that RF = 1 for all releases (Assumption 4.3.5), the airborne respirable normal release rate, Rr is therefore equal to the total normal release rate (R), and is calculated as

$$Rr = R = Q\ F\ ARF\ LPF \qquad \text{(Eq. 1B)}$$

The parameters used in the release calculation are supported by appropriate data or are in accordance with appropriate NRC regulatory guides, standard review plans, and Interim Staff Guidance documents, or are based on experience at operating nuclear power plants and related nuclear facilities.

3.2 SUBSURFACE FACILITIES

The primary confinement system for the subsurface repository is the waste package emplaced in the repository drifts. The secondary confinement consists of the natural barrier formed by the host rocks in the emplacement drifts and the underground bulkheads, which separate the emplacement and development areas.

Under normal operations of the subsurface repository, there are three potential mechanisms that would generate airborne releases of radioactive materials: resuspension of radioactive contamination from the external surfaces of the emplaced waste packages, neutron activation of ventilating air inside the emplacement drifts, and neutron activation of removable host rocks inside the emplacement drifts.

3.2.1 Resuspension of Waste Package Contamination

The potential airborne release due to resuspension of contamination on waste packages has been derived in *Recommended Surface Contamination Limits for Waste Packages Prior to Placement in the Repository* (Edwards and Yuan 2003, Equation 3). The release rate, R_c, may be calculated by:

$$R_c = M\ C_s\ A \qquad \text{(Eq. 2)}$$

where

A = Surface area of the average waste package (m^2)

M = Rate of waste package emplacement or number of waste packages emplaced per year (1/yr)

C_s = Average contamination level on the surface of waste packages during emplacement (Ci/m^2).

3.2.2 Release of Activation Products

The potential activation product concentrations and release rates have been documented in *Radiological Releases Due to Air and Silica Dust Activation in Emplacement Drifts* (BSC 2003a). The equations and parameters developed in that document are used here to calculate neutron activation product release rates from the subsurface exhaust shafts.

3.2.3 Activation in Air

The activation product concentration in air is calculated (BSC 2003a, Equation 3) as:

$$A = \frac{G\,(1 - e^{-\lambda Ti})\,e^{-\lambda Te}}{3.7E04} \qquad \text{(Eq. 3)}$$

where

A	=	Activity concentration in air (μCi/cm^3)
G	=	Activation product production rate inside emplacement drift =ΣΦ
Σ	=	Macroscopic activation cross section (1/cm)
Φ	=	Neutron flux (n/cm^2-s)
λ	=	Decay constant (1/s)
Ti	=	Irradiation time for ventilating air inside emplacement drift (s) = V/U
V	=	Air volume of emplacement drifts (m^3)
U	=	Airflow rate inside emplacement drift (m^3/s)
Te	=	Decay time following irradiation or air travel time from the outlet of the emplacement drift to the shaft exhaust point (s)
3.7E04	=	Conversion constant (disintegrations/s per μCi).

In Equation 3, ΣΦ represents the activation production rate.

Equation 4 is used to calculate the activation product release rates from the exhaust shafts. The annual release is the product of the release concentration and annual total exhaust air volume:

$$R_a = V\,A \qquad \text{(Eq. 4)}$$

where

R_a	=	release rate at the exhaust shaft (Ci/yr)
V	=	airflow rate at the exhaust shaft (m^3/yr)
A	=	activity concentration in air (Ci/m^3).

3.2.4 Activation in Dust

The release rates of the activation products in dust from the exhaust shafts are calculated as:

$$R_d = M_d\,C_d\,e^{-\lambda Te} \qquad \text{(Eq. 5)}$$

where

R_d	=	dust activation product release rate from exhaust shaft (Ci/yr)
C_d	=	saturated neutron activation product concentrations in the host rock (Ci/g)

M_d = limiting dust release rate (g/yr).

The decay time, Te, represents the air travel time from the emplacement drift outlet to the exhaust shaft exit.

3.3 ATMOSPHERIC DISPERSION FACTORS

The annual average atmospheric dispersion factors (χ/Qs) used in this calculation were generated in *GROA Airborne Release Dispersion Factor Calculation* (BSC 2005a) using the NRC-sponsored computer code, Atmospheric Relative CONcentrations in Building Wakes, V.96 (ARCON96) (Ramsdell and Simonen 1997). The annual average χ/Q value represents the average dilution of an airborne contamination due to atmospheric mixing and turbulence based on the site-specific atmospheric conditions, the relative configuration of the release point and the receptor, and the distance from the release point to the receptor of interest. The annual average χ/Q value is used to determine the dose consequences for a receptor based on the quantity released, atmospheric conditions, the distance to the receptor.

3.4 WORKER DOSE

The worker inhalation dose from normal operational releases is calculated as (NRC 2003, p. 9):

$$CEDE_i \text{ or } CDE_i = C_i \text{ B-Rate } T \; DCF_i \; U \qquad \text{(Eq. 6)}$$

where

$CEDE_i$ = committed effective dose equivalent from radionuclide *i* (rems)

CDE_i = committed dose equivalent for an internal organ from radionuclide *i* (rems)

C_i = airborne concentration of radionuclide *i* to which the worker is exposed (Ci/m^3)

= R_i (χ/Q)

R_i = rate of radionuclide *i* released to the air (Ci/s)

(χ/Q) = atmospheric dispersion factor, (s/m^3)

B-rate = worker breathing rate, 3.33×10^{-4} m^3/s (10 CFR 20, Appendix B)

DCF_i = inhalation dose conversion factor for radionuclide *i*

T = duration of the exposure (hrs);

= 2,000 hours for routine releases;

= number of hours in a work year

U = unit conversion factor if required.

The worker deep dose equivalent (DDE_i) and the shallow dose equivalent (SDE_i – for the skin dose) from air immersion exposure are calculated by (NRC 2003, p. 10):

$$DDE_i \text{ or } SDE_i = C_i \; DCF_i \; T \; U \qquad \text{(Eq. 7)}$$

where

DDE_i	=	DDE from radionuclide *i* (rems)
SDE_i	=	skin or shallow dose equivalent from radionuclide *i* (rems)
C_i	=	total airborne concentration of radionuclide *i* to which the worker is exposed (Ci/m^3)
	=	$R_i (\chi/Q)$
R_i	=	rate of radionuclide *i* released to the air (Ci/s)
DCF_i	=	air immersion dose conversion factor for radionuclide *i*
(χ/Q)	=	atmospheric dispersion factor (s/m^3)
T	=	duration of the exposure (s)
U	=	unit conversion factor if required.

The total effective dose equivalent (TEDE) is calculated by summing the component doses from inhalation and immersion (NRC 2003, p. 10):

$$TEDE = \sum_i CEDE_i + \sum_i DDE_i \qquad \text{(Eq. 8)}$$

For a given organ, the total organ dose equivalent (TODE) is calculated as (NRC 2003, p. 10):

$$TODE = \sum_i CDE_i + \sum_i DDE_i \qquad \text{(Eq. 9)}$$

The total skin dose equivalent (SDE) is the sum of individual nuclide doses (NRC 2003, p. 10):

$$SDE = \sum_i SDE_i \qquad \text{(Eq. 10)}$$

The lens dose equivalent (LDE) is calculated by summing the SDE and the TEDE (LDE = SDE + TEDE). This approach is consistent with guidance provided by the NRC (NRC 2003, p. 10).

3.4.1 Dose Conversion Factors

3.4.1.1 External Dose Conversion Factors

External dose conversion factors for immersion in air are taken from the U.S. Environmental Protection Agency Federal Guidance Report No. 12 (Eckerman and Ryman 1993, Table III.1).

3.4.1.2 Inhalation Dose Conversion Factors

Two sets of inhalation dose factors are used in this document for dose consequence comparison. They are:

(1) Inhalation dose factors taken from Federal Guidance Report (FGR) No. 11 (Eckerman et al. 1988, Table 2.1).

(2) Inhalation dose factors taken from ICRP Publication 68 (ICRP (International Commission on Radiological Protection) 1995, Tables B.1 and C.1) and *The ICRP Database of Dose Coefficients: Workers and Members of the Public.* Version 1.0. (ICRP 1999).

Dose factors corresponding to the f_1 values of oxides as specified in ICRP Publication 68 (ICRP 1995, Table 4) for Co-60 and Plutonium isotopes are used to represent the chemical form of spent fuel. Otherwise, the bounding dose conversion factors (DCFs) are used for each nuclide unless justification is made for an alternate value. The DCFs for particulate radionuclides are the bounding ones between activity median aerodynamic diameters (AMAD) of 1 and 5 μm.

3.4.2 Annual Average Radionuclide Concentration

The annual average radionuclide concentration at a receptor location, C_i (Ci/m^3), due to release from a release point is calculated as:

$$C_i = 3.17 \times 10^{-8} \; Q_i \, (\chi / Q) \qquad \text{(Eq. 11)}$$

where

C_i	=	annual average concentration of radionuclide *i* (Ci/m^3)
(χ/Q)	=	annual average atmospheric dispersion factor at a receptor from the release point (s/m^3)
Q_i	=	release rate of radionuclide *i* from the release point (Ci/yr)
3.17×10^{-8}	=	conversion from second to year (yr/s)
	=	1/[365 d/yr × 24 hr/d × 3,600 s/hr].

4. DESIGN INPUTS

This section identifies design parameters and assumptions for calculating dose consequence.

4.1 SURFACE FACILITY DESIGN PARAMETERS

The design parameters used for surface facility calculations are identified and provided in the following sections.

4.1.1 Design Average Fuel Source Terms

Design average fuel source terms (fission gases, volatiles, and fuel particulates) are taken from *PWR Source Term Generation and Evaluation* (BSC 2004a, Attachment IX). The average pressurized water reactor (PWR) fuel source terms were derived based on 4 percent initial enrichment, 48 GWd/MTHM burnup, 0.475 MTHM per fuel assembly, and a 25-year decay period (BSC 2004a, p. 27). The average PWR fuel data is used, conservatively, for estimating normal releases because it results in higher release dose consequence as compared to average boiling water reactor (BWR) fuel.

4.1.2 Radiological Parameters

Source term radionuclides are based on selection criteria in NUREG-1567 (NRC 2000, p. 9-11) and "Interim Staff Guidance – 5" (NRC 2003, Attachment, Section 3). For confinement analysis, the source term, as a minimum, includes activity from Co-60 in the crud, activity from iodine, other fission products that contribute greater than 0.1 percent of design basis fuel activity, and actinide activity that contributes greater than 0.01 percent of the design basis activity. Attachment I, Tables I-1 (PWR) and I-2 (BWR) present the individual radionuclide activity and its contribution in percent for source term nuclides. C-14 and Cl-36 are included in the source term table because of a potential release into the atmosphere as gaseous radionuclides. As shown on Table I-3, the source term nuclides contribute more than 99% of the calculated total dose.

4.1.3 Design Waste Receipt Rates

The nominal waste receipt rates are specified in the *Civilian Radioactive Waste Management System Requirements Document* (DOE 2004b, Tables 1 and 2). The highest rate of receipt for the repository is 3,000 MTHM per year. The receipt rate for each identical dry transfer facility, therefore, is 1,500 MTHM per year (BSC 2005d, 3.1.1.3.5). The nominal annual capacity and rate of receipt for the FHF is 600 MTHM, which represents the capacity required for the second year of the repository as presented in DOE 2004b (Tables 1 and 2). This input is used in Table 9 and Table I-3 for release calculations, and Tables 12a and 12b for calculating doses from FHF releases.

4.1.4 Release of Strontium

Strontium isotopes including Sr-90 are treated as fuel particles. This design input is based on the results of an analysis made in BSC 2004b (6.2.1.2 and Table 10) and is used in Table 8 for strontium release fraction.

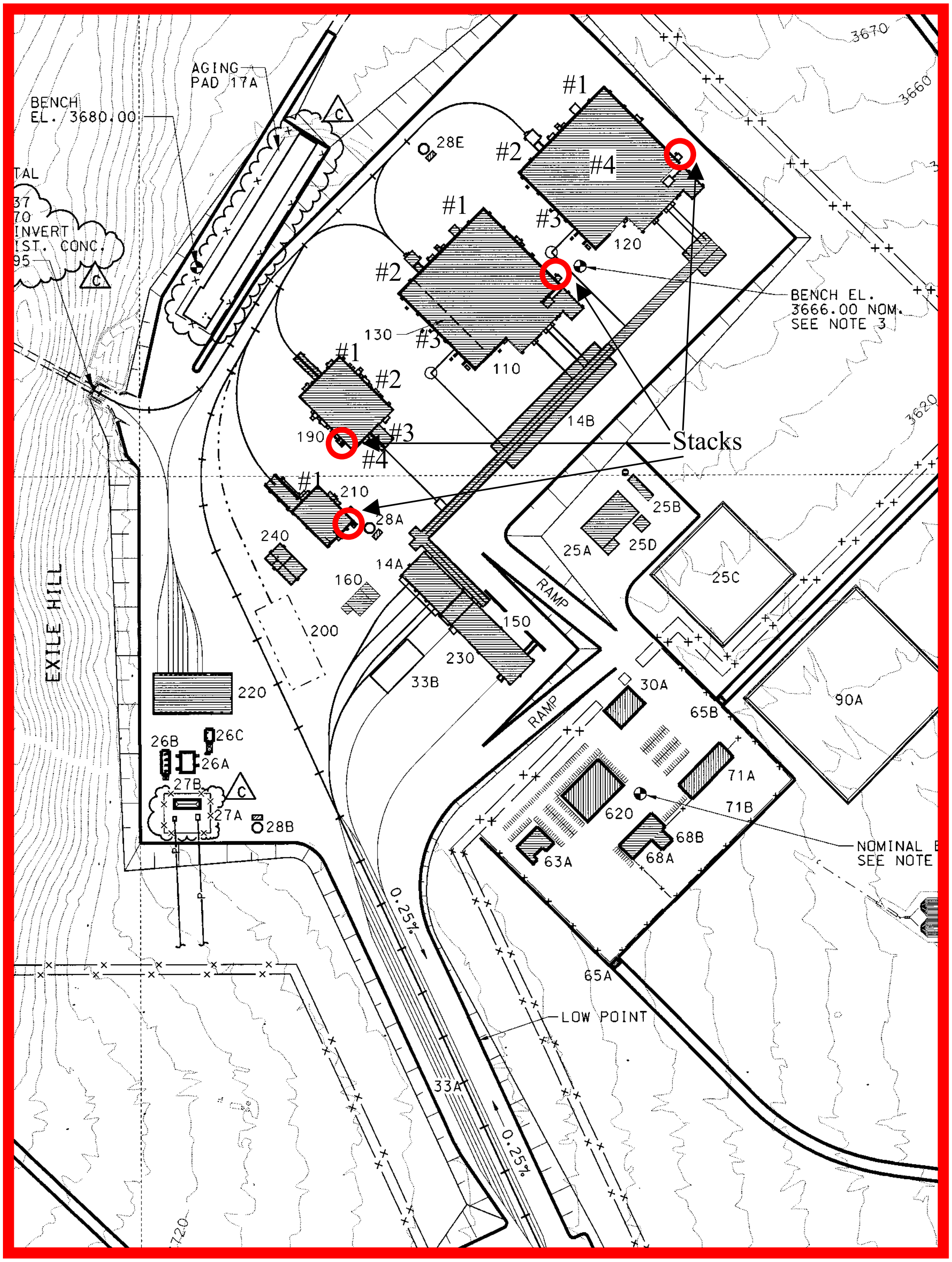
4.1.5 Surface Facility Atmospheric Dispersion Factors (χ/Q)

Maximum atmospheric dispersion factor values, χ/Qs, of potential receptors on-site for release from DTF1, DTF2 and FHF are presented in Table 1 (see Figure 1). These values are taken from *GROA Airborne Release Dispersion Factor Calculation* (BSC 2005a, Tables 4, 5 and 17) and are used in Section 6.1 to calculate the maximum worker dose consequences for releases from Dry Transfer Facility 1, Dry Transfer Facility 2 and Fuel Handling facility, respectively.

Table 1. Surface Release Maximum Atmospheric Dispersion Factors (χ/Qs)

Maximum Receptor Location	χ/Q (s/m3) due to release from		
	DTF1	DTF2	FHF
[a]Dry Transfer Facility #1 (110) [b]Dry Transfer Facility #2 (120)	4.7E-05[b]	1.8E-05[b]	2.8E-05[a]

Source: BSC 2005a, Tables 4 (DTF1), 5 (DTF2) and 17 (FHF).



Source: BSC 2005a, Figure II-1.

Figure 1. Surface Facility Release and Receptor Locations

4.2 SUBSURFACE FACILITY DESIGN PARAMETERS

The design parameters used for subsurface facility calculations are provided in this section.

4.2.1 Emplacement Drift Ventilation Rates

Emplacement drift ventilation airflow rates, taken *Underground Layout Configuration* (BSC 2003b, Section 8.6), are:

- Emplacement drift airflow intake rate: 15 m^3/s
- Emplacement drift airflow output rate: 17 m^3/s.

This input is used in Attachment III to calculate the average emplacement drift airflow rate.

4.2.2 Emplacement Drift Length

The average emplacement drift length calculated by BSC (2003a, Section 5.4.1) is used to estimate air irradiation time during transport through emplacement drifts. The average length is conservatively rounded to 600 meters (from 572.7 meters). This input is used in Attachment III to calculate air volume of the emplacement drift.

4.2.3 Emplacement Drift Airway Area

The emplacement drift airway area is taken from *Ventilation Network Model Calculation* (BSC 2003c, Table 5). With waste packages loaded, the area is 12.31 m^2. This input is used in Attachment III to calculate air volume of the emplacement drift. The information provided by BSC (2003c) is appropriate because the calculated dose is so low (see Section 7.2) that a conventional-quality engineering estimate is sufficient to support the conclusions of the dose evaluations.

4.2.4 Minimum Length and Airflow from Emplacement Drift Outlet to Shaft Exhaust

The minimum lengths and airflow from emplacement drift outlet to shaft exhausts (Figure 2) are taken from *Ventilation Network Model Calculation* (BSC 2003c, Attachment D) and are provided in Table 2. The information provided by BSC (2003c) is appropriate because the calculated dose is so low (see Section 7.2) that a conventional-quality engineering estimate is sufficient to support the conclusions of the dose evaluations.

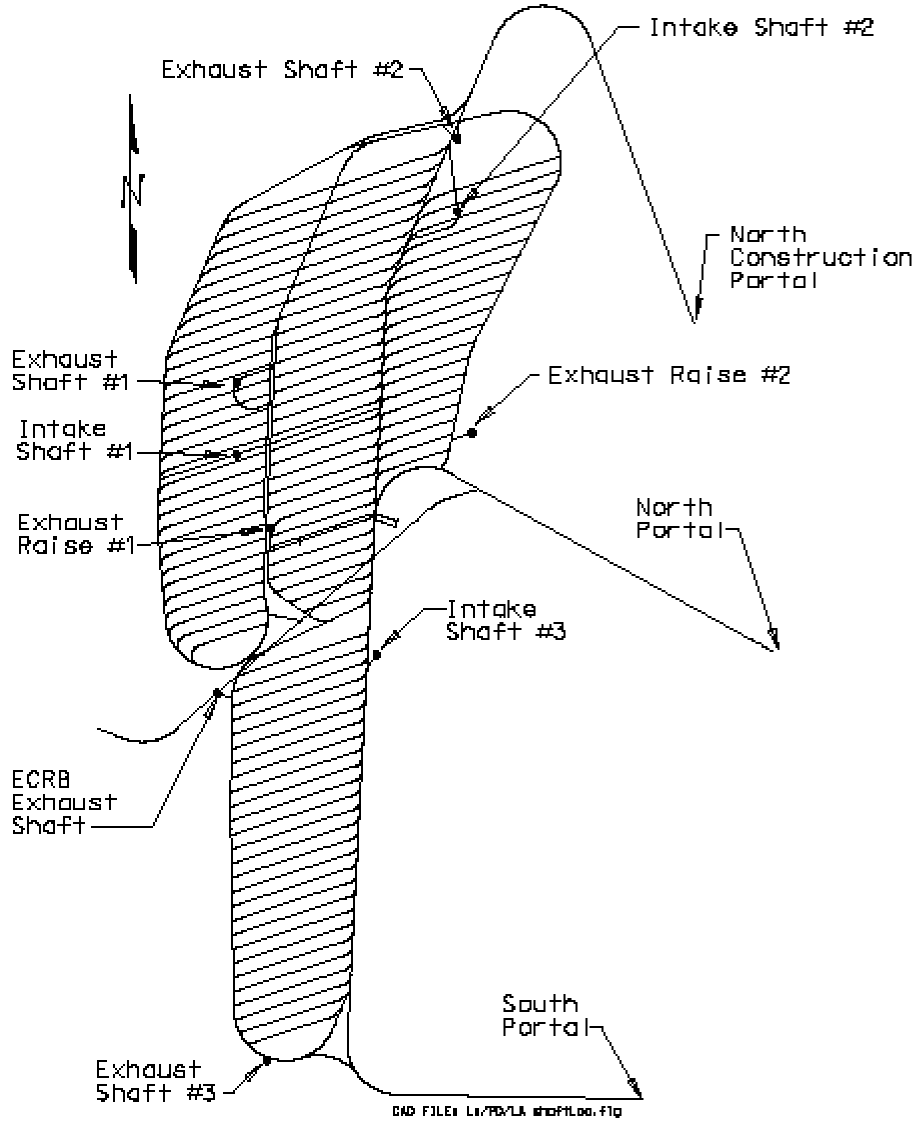
Table 2. Minimum Length, Airflow, and Travel Time from Emplacement Drift Outlet to Release

Shaft Exhaust [a]	**Branch No.**[a]	**Length** [a] **(ft)**	**Length (m)**	**Airflow** [a] **(kcfm)**	**Airflow (cms)**	**Cross** [a] **Section Area (ft^2)**	**Cross Section Area (m^2)**	**Travel Time (s)**
Exhaust Raise #1	1	1,217	371	392	185	162	15	30
	18	45	14	168	79	208	19	3
Total Time								**33**
Exhaust Raise #2	185	915	279	391	185	162	15	23
	184	417	127	391	185	208	19	13
	393	133	41	344	163	393	37	9
Total Time								45
Exhaust Shaft #1	25	1,436	438	812	383	451	42	48
	26	812	247	406	192	620	58	74
	365	133	41	61	29	393	37	52
Total Time								174
Exhaust Shaft #2	28	1,404	428	812	383	451	42	47
	503	32	10	800	377	451	42	1
	29	387	118	404	191	620	58	36
	489	1,500	457	496	234	393	37	71
	325	269	82	486	230	393	37	13
Total Time								168
Exhaust Shaft #3	181	958	292	726	343	451	42	36
	182	66	20	726	343	620	58	3
	460	269	82	712	336	393	37	15
Total Time								54
ECRB Exhaust Shaft	32	1,306	398	832	393	451	42	43
	461	108	33	514	243	451	42	6
	180	299	91	514	243	620	58	22
	292	70	21	327	154	393	37	5
Total Time								76

Source: [a] BSC 2003c, Attachment D.

NOTE: ECRB = enhanced characterization of the repository block (drift)

This design input is used in Attachment III to calculate air travel time following irradiation release of neutron activation products from drifts.



Source: BSC 2003b, Figure 10.

Figure 2. Subsurface Air Intake and Exhaust Locations

4.2.5 Rock Density

The density of the rock is 2.5 g/cm^3 based on mean particle density in the four lithostratigraphic layers of the repository (Tptpul, Tptpmn, Tptpll, and Tptpln) (BSC 2004c, Section 6.1.6 and Table 5-4). This input is used in Table 5 to calculate the activation product concentration in rock.

4.2.6 Waste Package Contamination Parameters

Table 3 presents the derived radioactive contamination levels that are used to demonstrate compliance for admitting waste packages into the emplacement drifts. These derived contamination levels represent the average concentrations of radioactivity on the external surfaces of waste packages that should not be exceeded before the waste package is transported to the subsurface repository. The derivation of these levels is based on a waste package surface area of 32 m^2 (Edwards and Yuan, 2003, Section 4.2.1) the requirement that the annual average concentrations of radioactive material released at the repository shaft exhaust do not exceed the airborne effluent concentration limits specified in 10 CFR Part 20, Appendix B.

The derived contamination values for gross alpha and gross beta/gamma activities, respectively, are 1.1×10^{-8} Ci/m^2 and 3.4×10^{-6} Ci/m^2.

Table 3. Derived Contamination Values

	Derived Average Radioactive Contamination Level [a] (Ci/m^2)
Alpha-emitting nuclides (G_α)	1.1E-8
Beta/Gamma emitting nuclides (G_β)	3.4E-6

NOTE: Source: Edward and Yuan 2003, Table 3.

[a] Derived levels was based on an exhaust ventilation flow rate of 340 m^3/s. For other exhaust flow rates (V), the derived contamination levels should be multiplied by a flow-rate-adjusting factor φ =V (m^3/s)/340.

This input is used in Section 6.2.1 and Attachment II to calculate the resuspension release of waste package contamination.

4.2.7 Neutron Activation Reaction Rates in Air

Table 4 presents the neutron activation reaction rates for N-16 and Ar-41 in subsurface emplacement drifts air. These reaction rates are used in Attachment III to calculate air activation product release rates from the subsurface exhausts.

Table 4. Neutron Activation Reaction Rates of Air in Emplacement Drifts

Neutron Activation Reaction Rates		
Activation Product [a]	Rates (reactions/cm^3-s) [a]	Half Life [b]
N-16	3.3E-06	7.13 sec
Ar-41	2.7E-04	1.82 hr

Source: [a] BSC 2003a, Table 5-8.
[b] Parrington et al. 1996, pp. 19 and 23.

4.2.8 Saturated Activation Product Concentration in Host Rock

The saturated activation product concentrations in dust suspended from the host rock in the emplacement drifts are taken from BSC (2003a, Table 5-11) and are shown in Table 5. This input is used in Attachment III to calculate the dust activation product release rates.

Table 5. Rock Dust Activity Concentrations

Activation Product		Saturated Activity in Host Rock	
(1) Nuclide [a]	(2) Half Life [b]	(3) (μCi/cm^3) [a]	(4) (μCi/g)
N-16	7.13 sec	2.1E-07	8.4E-08
Na-24	14.96 hr	3.7E-05	1.5E-05
Al-28	2.25 min	3.9E-05	1.6E-05
Si-31	2.62 hr	5.3E-06	2.1E-06
K-42	12.36 hr	8.0E-06	3.2E-06
Fe-55	2.73 yr	8.2E-07	3.3E-07

NOTES: [a] BSC 2003a, Table 5-11.
[b] Parrington et al. 1996, pp. 19-25.
(4) = (3)/2.5 (density of rock, Section 4.2.5).

4.2.9 Subsurface Facility Atmospheric Dispersion Factors (χ/Q)

Maximum atmospheric dispersion factor values, χ/Qs, of potential receptors on-site for subsurface release consequence calculation are presented in Table 6. These values are selected from *GROA Airborne Release Dispersion Factor Calculation* (BSC 2005a, Tables 18 through 23). The χ/Q value of 1.5×10^{-5} s/m^3 is used in Section 6.2 to calculate the maximum receptor concentrations from subsurface releases. This χ/Q value represents the maximum receptor dispersion factor estimated for intake shaft #1, which is about 410 m from exhaust shaft #1. This input is used in Section 6.2 and Section 7 (Table 14) for calculating maximum receptor air concentrations.

Table 6. Subsurface Release Atmospheric Dispersion Factors (χ/Qs)

Release Source	**ECRB Exhaust Shaft**	**Exhaust Raise #1**	**Exhaust Raise #2**	**Exhaust Shaft #1**	**Exhaust Shaft #2**	**Exhaust Shaft #3**
Max. Receptor	South Portal	Intake Shaft #1, Intake Shaft #3	North Portal	Intake Shaft #1	Intake Shaft #2	South Portal
Max. χ/Q (s/m^3)	1.4E-06	5.0E-06	2.0E-06	**1.5E-05**	1.4E-05	1.0E-06

Source: BSC 2005a, Tables 18 through 23

NOTE: ECRB = enhanced characterization of the repository block (drift)
1.5E-5 is bolded to indicate maximum χ/Q among all receptors

4.3 SURFACE FACILITY BOUNDING ASSUMPTIONS

The following bounding assumptions are used for the calculation of airborne releases from the surface facilities.

4.3.1 Source Term for Crud

The crud activities per fuel assembly for Co-60 and Fe-55 are assumed to be 2.35 Ci and 4.64 Ci, respectively, at 25 years following discharge.

These crud activities are taken from BSC 2004a (Attachment VI) and were calculated using conservatively estimated crud surface activity and bounding surface area of a South Texas PWR assembly. This assumption is used in Section 6.1.1 (Table 9) and Table I-3 for crud release calculations.

4.3.2 Failed Fractions

For normal operations, an average of one percent of the fuel rods received are assumed to develop cladding breaches (F = 0.01) that could cause the release of gases, volatiles, and particulates in the gap region. All radionuclides present in the fuel rod gap are assumed to be released in the event of a cladding breach.

This assumption is consistent with the failed fractions assumed in guidance documents NRC (2000, p. 9-12) and NRC (2003, Attachment, Table 7.1). This assumption is used in Section 6.1.1 (Table 9) and Table I-3 for release calculations.

4.3.3 Airborne Release Fractions

Of the total fuel assembly radioactive inventory, the following airborne release fractions (ARF) are assumed to be present in the fuel rod gap:

- 0.3 of fission gases (H-3, C-14, Cl-36, Kr-85, and I-129)
- 2×10^{-4} for volatile materials (Cs-137)
- 3×10^{-5} for fuel particles.

These airborne release fractions are based on guidance established by the NRC in NUREG-1567 (NRC 2000, p. 9-12) and ISG-5 (NRC 2003, Attachment, Table 7.1). This assumption is used to determine release fractions in Table 8.

4.3.4 Release of Crud

Fifteen percent of the crud surface contamination is assumed to become loose from the fuel surfaces and 10 percent of the loose crud is assumed to become airborne and released during normal operations. The 15 percent loose fraction is based on guidance provided by the NRC in NUREG-1567 (NRC 2000, p. 9-12) and ISG-5 (NRC 2003, Attachment, Table 7.1). The 10 percent airborne release fraction represents the bounding release fraction for the case when venting gases pressurize the volume in which loose powdering surface contamination exists (DOE 1994, p. 5-22). This 10 percent ARF also bounds ARFs for other potential release mechanisms such as venting of pressurized powders or pressurized gases through a powder (DOE 1994, 4.4.2.3) and suspension of surface contamination from solid material by impact and vibration shock (DOE 1994, pp. 5-7 and 5-24). This assumption is used in Table 8 for crud release fraction.

4.3.5 Respirable Fractions

For estimating respirable concentrations, respirable fractions are conservatively assumed to be one for all releases.

This bounding assumption is used in Eq. 1B to indicate all releases are assumed respirable.

4.3.6 HEPA Filter System Efficiency

Two stages of the HEPA filter system are used for DTF and FHF primary confinement zone HVAC exhaust systems (BSC 2005c, 3.1.1.1.1). The design of the HVAC exhaust systems will use HEPA filters with removal efficiency of 99.97 percent on particles measuring 0.3 micrometers (BSC 2005c, 3.1.1.1.1). A LPF of 10^{-4} is assumed for a HEPA system containing two stages of HEPA filters in series. A leakpath factor of 10^{-4} is conservative, being greater than the more realistic value of 2×10^{-6} presented in *Nuclear Fuel Cycle Facility Accident Analysis Handbook* (SAIC 1998, Section F.2.1.3). Cesium isotopes are treated as volatile solid or particles when vent through the facility off-gas system. Test data conducted at a high temperature of 900°C (Lorenz et al. 1980, Table 19 and p. 48) show that two-stage HEPA filters capture almost 100% of incoming airborne cesium. The test temperature used bounds temperatures in a waste transfer cell under normal or accident conditions.

This assumption is used in Table 9 for off-gas leak path factor.

4.3.7 Repository Worker Work Hours

The repository worker is assumed to work full time (2,000 hours) at the repository site. This conservative assumption is used in Section 6.1.1 (Tables 10 and 11), and Tables I-3 and IV-1 for surface worker dose calculations.

4.3.8 Resuspension Rate

It is assumed in the cask contamination resuspension calculations that the resuspension rate is 4×10^{-5}/hr. This resuspension factor is the bounding value recommended for aerodynamic entrainment of powders from unyielding surfaces for indoors or outdoors exposed to ambient conditions following an event (DOE 1994, p. 5-7). This assumption is used in Section 6.1 to estimate cask contamination resuspension rates.

4.4 SUBSURFACE FACILITY BOUNDING ASSUMPTIONS

The following assumptions are used for the calculation of airborne releases from subsurface facilities.

4.4.1 Waste Package Emplacement Rate

The waste packages emplacement rate is assumed to be 600/yr. The bounding emplacement rate assumption of 600 waste packages per year is consistent with the assumption made in the *Recommended Surface Contamination Levels for Waste Packages Prior to Placement in the Repository* (Edwards and Yuan 2003, Section 4.2.2) and bounds those provided by Cloud 2003 (Table 4). This assumption is used in Section 6.2.1 and Attachment II to calculate resuspension release of waste package contamination.

4.4.2 Dust Emission Rate

Bounding dust emission rate to surface atmosphere is assumed to be 250 tons/yr. This rate is taken from the assumption made by BSC (2003a, Section 3.7), which was based on the emission guideline specified in 40 CFR 51.166(b)(1)(i)(*b*). This assumption is appropriate because it yields bounding estimates of activated dust release rates. This assumption is used in Attachment III.

4.4.3 Respirable Fraction

All released or suspended radioactive particles are assumed to be respirable. This assumption is used in Section 6.2 for dose calculations and is appropriate because it yields the most conservative dose value.

4.4.4 Subsurface Facility Worker Work Hours

The repository worker is assumed to work full time (2,000 hrs) at the repository site. This conservative assumption is used in Sections 6.2.3 and 7 and Tables 14a, 14b, 15 and IV-2 for surface worker dose calculations.

4.5 ASSUMPTIONS REQUIRING VERIFICATION

There are no assumptions that require verification.

4.6 REGULATIONS

4.6.1 10 CFR Part 63 and 10 CFR Part 20

Radiation dose limits for normal operations including Category 1 event sequences through permanent closure are specified in 10 CFR Part 63 and 10 CFR Part 20. These regulations, summarized below, specify worker dose limits during normal operations and for Category 1 event sequences.

Table 7a. Worker Dose Standards for Normal Operations and Category 1 Event Sequences

Event Sequence Type	Dose Type	Dose Standards[a]
Normal operations and Category 1 event sequences [Aggregate Radiation exposures for Category 1 event sequences per 10 CFR 63.111(b)(1)]	Annual TEDE during normal operations and for Category 1 event sequences	ALARA
	TEDE	5 rem/yr
	The highest of the TODE	50 rem/yr
	LDE	15 rem/yr
	SDE	50 rem/yr

Note: [a]10 CFR 20.1201 *Occupational Dose Limits for Adults*. TEDE = total effective dose equivalent; CDE = committed dose equivalent; LDE = lens dose equivalent; SDE = skin dose equivalent; TODE = total organ dose equivalent.

4.6.2 49 CFR 173.443 Contamination Control

The following table lists the maximum permissible limits on the exterior of a shipping package.

Table 7b. Non-Fixed External Radioactive Contamination-Wipe Limits

Contaminant	Maximum permissible limits		
	Bq/cm^2	μCi/cm^2	dpm/cm^2
Beta and gamma emitters and low toxicity alpha emitters	4	10^{-4}	220
All other alpha emitting radionuclides	0.4	10^{-5}	22

Source: 49 CFR 173.443, Table 9.

4.7 CRITERIA

As low as is reasonably achievable (ALARA) design goals (BSC 2004d, Section 4.9.3.3) for occupational workers ensure that individual and collective annual doses are maintained at ALARA levels during normal operations and as a result of Category 1 event sequences.

The ALARA design goal for individual radiation worker doses is to minimize the number of individuals that have the potential of receiving more than 500 mrem/yr TEDE. This goal is 10 percent of the annual TEDE limit in 10 CFR 20.1201 and includes internal and external exposures.

5. USE OF SOFTWARE

ICRP Database for Dose Coefficients Version 2.01 (STN: 71420-2.01-00, ICRP 1999), a commercial off-the-shelf software, is used in generating dose conversion factors in this document. ICRP Database was installed on a Dell Optiplex GX240 (CPU 150520) running Microsoft Windows 2000 Professional. The accuracy of the dose conversion factors (DCF) generated from this software is verified by comparing with the tabulated effective dose coefficients provided in ICRP Publication 68 (ICRP 1995, Tables B.1 and C.1).

Microsoft Excel 2000 is used to perform simple calculations. User-defined formulas, input, and results are documented in sufficient detail in Section 6 and the attachments to allow for independent duplication of the various computations without recourse to the originator.

ICRP Database for Dose Coefficients Version 2.01 and Microsoft Excel 2000 are exempt from the requirements of LP-SI.11Q-BSC, *Software Management* (Section 2.1.6).

6. CALCULATION

Potential airborne radionuclide release rates and worker doses are calculated using equations described in Section 3 and input parameters and assumptions detailed in Section 4.

6.1 SURFACE FACILITY RELEASE CALCULATION

The radionuclide release fractions used to perform release calculations are summarized in Table 8. The release fraction, except for crud, is a fraction of the total radionuclide inventory within a spent fuel rod, which is applicable only to the failed fuel rods in a fuel assembly. The release of radionuclides to the environment as a result of normal operations at the surface facilities is estimated from the release factors (Table 8) and from the annual schedule of receipts and shipments and the amount of spent fuel in storage. The calculation of the normal releases for the 1,500 MTHM throughput year per dry transfer facility is provided in Table 9. The radionuclides selected are those determined to be important for dose calculation based on the selection criteria described in Section 4.1.2.

The release of surface contamination from the shipping casks is negligible compared to direct releases from failed spent nuclear fuel. SNF casks accepted at the Dry Transfer Facility are expected to meet the 49 CFR 173.443 (Table 9) external contamination limits (Section 4.6.2). Based on these limits, the bounding allowable removable surface contamination is 10^{-4} μCi/cm^2 for beta and gamma emitters and 10^{-5} μCi/cm^2 for alpha emitters.

The resuspension release of cask contamination is estimated by multiplying the surface contamination limits by the combined surface area of 3 rail transportation casks (2 in the DTF 1 process lines and 1 in the dry cell of the remediation facility), and a resuspension rate of 4×10^{-5}/hr [Assumption 4.3.8] to get 5.3×10^{-5} Ci/yr of beta and gamma emitters (10^{-4} μCi/cm^2 $\times$ 10^{+4} cm^2/m^2 $\times$ 10^{-6} Ci/μCi $\times$ 51 m^2/cask $\times$ 4×10^{-5}/hr $\times$ 3 casks $\times$ 365 d/yr $\times$ 24 hr/d) and 5.3×10^{-5} Ci/yr of alpha emitters. The 5.3×10^{-5} Ci/yr release rate of beta and gamma emitters is negligible as compared to 260, 26 and 110 Ci/yr, respectively, of Cs-137, Sr-90 and crud Co-60 release rates estimated in Table 9 (column 6) for the major beta and gamma emitters from a DTF. The 5.3×10^{-6} Ci/yr alpha emitters release rate is negligible as compared to the 2.2, 1.9 and 1.3 Ci/yr, respectively, of Pu-238, Am-241 and Cm-244 release rates estimated also in Table 9 for processing of SNF at a DTF. The cask surface area of 51 m^2 per cask represents the dimensions of a typical rail transportation cask with 100 inches in diameter and 200 inches in length (BSC 2003e, Table 2-4) [(3.1416 × 100 in × 200 in × 0.0254 × 0.0254) + (2 × 3.1416 × 100 in × 100 in /4 × 0.0254 × 0.0254)].

The surface contamination airborne release from casks therefore is negligible and not included in the dose calculations.

Table 8. Airborne Release Fractions by Radionuclide Group

Radionuclide Group		Release Fraction [a]
Gases	Tritium (H-3) Carbon-14 (C-14) Clorine-36 (Cl-36)	0.3
	Noble Gas (Kr-85)	0.3
	Iodine (I-129)	0.3
Volatiles	Cesium (Cs-137)	2×10^{-4}
Crud	Cobalt (Co-60)	0.015 [b]
Fuel Fines	Strontium (Sr-90) [c]	3×10^{-5}
	Particulates	3×10^{-5}

NOTES: [a] Source: Assumption 4.3.3
[b] Source: Assumptions 4.3.4
[c] Source: Section 4.1.4.

6.1.1 Worker Dose Calculation

Potential maximum worker doses resulting from releases at the surface facilities are calculated in this section using the equations presented in Section 3.4.

Calculations of annual doses (in mrem/yr) received by a worker per unit dispersion factor for release from a Dry Transfer Facility are shown in Tables 10a (FGR-11) and 10b (ICRP-68) for TEDE and Tables 11a (FGR-11) and 11b (ICRP-68) for TODE, SDE and LDE. Dose calculations are made for a full time worker (2,000 hr/yr, Assumption 4.3.7). Calculations of annual doses to the maximally exposed workers for releases from the three transfer facilities are shown in Tables 12a (FGR-11) and 12b (ICRP-68). The dose calculations can be performed for all other receptors of concern by applying the appropriate χ/Q value from Table 1 to the calculated doses per unit dispersion factor (χ/Q) presented in Tables 12 (a, b).

Table 9. Dry Transfer Facility Normal Operation Annual Release (1500 MTHM/yr Throughput)

Radionuclide	Source Term	Annual Throughput	Failed FA Ci/yr	Gap Release Fraction	Release to Off-Gas	Off-Gas Leak Path Factor	Release from Off-Gas
Average PWR	Ci/FA	Ci/yr	1.0% Cladding Breaches for nuclides in fuel	Table 8	Ci/yr	--	Total Ci/yr
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H-3	1.1E+02	3.6E+05	3.6E+03	3.00E-01	1.1E+03	1.0E+00	1.1E+03
C-14	3.3E-01	1.0E+03	1.0E+01	3.00E-01	3.1E+00	1.0E+00	3.1E+00
Cl-36	6.8E-03	2.1E+01	2.1E-01	3.00E-01	6.4E-02	1.0E+00	6.4E-02
Kr-85	1.1E+03	3.6E+06	3.6E+04	3.00E-01	1.1E+04	1.0E+00	1.1E+04
I-129	2.2E-02	6.9E+01	6.9E-01	3.00E-01	2.1E-01	1.0E+00	2.1E-01
Cs-137	4.1E+04	1.3E+08	1.3E+06	2.00E-04	2.6E+02	1.0E-04	2.6E-02
Crud Co-60	2.3E+00	7.4E+03	7.4E+03	1.50E-02	1.1E+02	1.0E-04	1.1E-02
Fuel Co-60	3.1E+02	9.9E+05	9.9E+03	3.00E-05	3.0E-01	1.0E-04	3.0E-05
Ni-63	2.5E+02	8.0E+05	8.0E+03	3.00E-05	2.4E-01	1.0E-04	2.4E-05
Sr-90	2.7E+04	8.6E+07	8.6E+05	3.00E-05	2.6E+01	1.0E-04	2.6E-03
Pm-147	1.2E+02	3.8E+05	3.8E+03	3.00E-05	1.1E-01	1.0E-04	1.1E-05
Sm-151	2.1E+02	6.7E+05	6.7E+03	3.00E-05	2.0E-01	1.0E-04	2.0E-05
Eu-154	6.7E+02	2.1E+06	2.1E+04	3.00E-05	6.4E-01	1.0E-04	6.4E-05
Pu-238	2.3E+03	7.2E+06	7.2E+04	3.00E-05	2.2E+00	1.0E-04	2.2E-04
Pu-239	1.8E+02	5.6E+05	5.6E+03	3.00E-05	1.7E-01	1.0E-04	1.7E-05
Pu-240	3.2E+02	1.0E+06	1.0E+04	3.00E-05	3.0E-01	1.0E-04	3.0E-05
Am-241	2.0E+03	6.3E+06	6.3E+04	3.00E-05	1.9E+00	1.0E-04	1.9E-04
Pu-241	2.5E+04	7.8E+07	7.8E+05	3.00E-05	2.3E+01	1.0E-04	2.3E-03
Am-243	2.2E+01	6.9E+04	6.9E+02	3.00E-05	2.1E-02	1.0E-04	2.1E-06
Cm-243	1.0E+01	3.3E+04	3.3E+02	3.00E-05	9.8E-03	1.0E-04	9.8E-07
Cm-244	1.4E+03	4.3E+06	4.3E+04	3.00E-05	1.3E+00	1.0E-04	1.3E-04
Total Activity	1.0E+05	3.2E+08	3.2E+06	--	1.2E+04	--	1.2E+04

NOTES: (1) & (2) Source: Table I-1. For crud Co-60: Assumption 4.3.1
(3) (2) × 1,500 MTHM / 0.475 MTHM/FA (Sections 4.1.1 and 4.1.3)
(4) (3) × 0.01 (Assumption 4.3.2: 1 percent failed applicable to fuel nuclides only)
(5) Source: Table 8.
(6) (4) × (5)
(7) Assumption 4.3.6 and Section 4.1.4 for Cs release from off-gas.
(8) (6) × (7)
FA = fuel assembly.

Table 10a. Worker TEDE Calculation (1500 MTHM/yr Throughput, FGR-11 Dose Factors, χ/Q = 1)

Radio-nuclide	**Annual Release**	**Release Rate**	**Air Concentration**	**DCF Effective**	**Inhalation Dose (CEDE)**	**Submersion Dose Factor**	**Submersion Dose (DDE)**	**Total Dose (TEDE)**
	Ci/yr	Ci/s	Ci/m^3	rem/Ci	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/ year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
H-3	1.1E+03	3.4E-05	3.4E-05	6.4E+01	5.3E+03	1.2E-06	3.0E-01	5.3E+03
C-14	3.1E+00	1.0E-07	1.0E-07	2.4E+01	5.6E+00	8.3E-07	6.0E-04	5.6E+00
Cl-36	6.4E-02	2.0E-09	2.0E-09	2.2E+04	1.1E+02	8.3E-05	1.2E-03	1.1E+02
KR-85	1.1E+04	3.4E-04	3.4E-04	0.0E+00	0.0E+00	4.4E-04	1.1E+03	1.1E+03
I-129	2.1E-01	6.6E-09	6.6E-09	1.7E+05	2.8E+03	1.4E-03	6.7E-02	2.8E+03
Cs-137	2.6E-02	8.2E-10	8.2E-10	3.2E+04	6.3E+01	1.0E-01	6.0E-01	6.4E+01
Crud Co-60	1.1E-02	3.5E-10	3.5E-10	2.2E+05	1.9E+02	4.7E-01	1.2E+00	1.9E+02
fuel Co-60	3.0E-05	9.4E-13	9.4E-13	2.2E+05	4.9E-01	4.7E-01	3.2E-03	5.0E-01
Ni-63	2.4E-05	7.6E-13	7.6E-13	2.3E+03	4.2E-03	0.0E+00	0.0E+00	4.2E-03
Sr-90	2.6E-03	8.2E-11	8.2E-11	1.3E+06	2.5E+02	7.3E-04	4.3E-04	2.5E+02
Pm-147	1.1E-05	3.6E-13	3.6E-13	3.9E+04	3.3E-02	2.6E-06	6.6E-09	3.3E-02
Sm-151	2.0E-05	6.3E-13	6.3E-13	3.0E+04	4.6E-02	1.3E-07	6.1E-10	4.6E-02
Eu-154	6.4E-05	2.0E-12	2.0E-12	2.9E+05	1.4E+00	2.3E-01	3.3E-03	1.4E+00
Pu-238	2.2E-04	6.9E-12	6.9E-12	2.9E+08	4.8E+03	1.8E-05	8.9E-07	4.8E+03
Pu-239	1.7E-05	5.3E-13	5.3E-13	3.1E+08	3.9E+02	1.6E-05	6.0E-08	3.9E+02
Pu-240	3.0E-05	9.6E-13	9.6E-13	3.1E+08	7.1E+02	1.8E-05	1.2E-07	7.1E+02
Am-241	1.9E-04	5.9E-12	5.9E-12	4.4E+08	6.3E+03	3.0E-03	1.3E-04	6.3E+03
Pu-241	2.3E-03	7.4E-11	7.4E-11	4.9E+06	8.8E+02	2.7E-07	1.4E-07	8.8E+02
Am-243	2.1E-06	6.6E-14	6.6E-14	4.4E+08	7.0E+01	8.1E-03	3.8E-06	7.0E+01
Cm-243	9.8E-07	3.1E-14	3.1E-14	3.1E+08	2.3E+01	2.2E-02	4.8E-06	2.3E+01
Cm-244	1.3E-04	4.1E-12	4.1E-12	2.5E+08	2.4E+03	1.8E-05	5.3E-07	2.4E+03
Total Sum	1.2E+04	3.7E-04	--	--	2.4E+04	--	1.1E+03	2.5E+04

Notes: (1) Table 9, column (1)

(2) Table 9, column (8)

(3) (2) / 3,600 s/hr / 24 hr/d / 365 d/yr

(4) (3) × 1.0 s/m^3 (unit χ/Q)

(5) Table I-3, column (12)

(6) Equation 6 (with T = 2,000 hours/yr, Assumption 4.3.7): (4) × (5) × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(7) Table I-3, column (13)

(8) (4) (Ci/m^3) × (7) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(9) (6) + (8).

Table 10b. Worker TEDE Calculation (1500 MTHM/yr Throughput, ICRP-68 Dose Factors, χ/Q = 1)

Radio-nuclide	Annual Release	Release Rate	Air Concentration	DCF Effective	Inhalation Dose (CEDE)	Submersion Dose Factor	Submersion Dose (DDE)	Total Dose (TEDE)
	Ci/yr	Ci/s	Ci/m^3	rem/Ci	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/ year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
H-3	1.1E+03	3.4E-05	3.4E-05	6.7E+01	5.5E+03	1.2E-06	3.0E-01	5.5E+03
C-14	3.1E+00	1.0E-07	1.0E-07	2.4E+01	5.8E+00	8.3E-07	6.0E-04	5.8E+00
Cl-36	6.4E-02	2.0E-09	2.0E-09	2.6E+04	1.3E+02	8.3E-05	1.2E-03	1.3E+02
KR-85	1.1E+04	3.4E-04	3.4E-04	0.0E+00	0.0E+00	4.4E-04	1.1E+03	1.1E+03
I-129	2.1E-01	6.6E-09	6.6E-09	3.6E+05	5.6E+03	1.4E-03	6.7E-02	5.6E+03
Cs-137	2.6E-02	8.2E-10	8.2E-10	2.5E+04	4.9E+01	1.0E-01	6.0E-01	5.0E+01
Crud Co-60	1.1E-02	3.5E-10	3.5E-10	1.1E+05	9.1E+01	4.7E-01	1.2E+00	9.2E+01
fuel Co-60	3.0E-05	9.4E-13	9.4E-13	1.1E+05	2.4E-01	4.7E-01	3.2E-03	2.5E-01
Ni-63	2.4E-05	7.6E-13	7.6E-13	7.4E+03	1.3E-02	0.0E+00	0.0E+00	1.3E-02
Sr-90	2.6E-03	8.2E-11	8.2E-11	5.6E+05	1.1E+02	7.3E-04	4.3E-04	1.1E+02
Pm-147	1.1E-05	3.6E-13	3.6E-13	1.7E+04	1.5E-02	2.6E-06	6.6E-09	1.5E-02
Sm-151	2.0E-05	6.3E-13	6.3E-13	1.4E+04	2.1E-02	1.3E-07	6.1E-10	2.1E-02
Eu-154	6.4E-05	2.0E-12	2.0E-12	1.9E+05	8.9E-01	2.3E-01	3.3E-03	9.0E-01
Pu-238	2.2E-04	6.9E-12	6.9E-12	5.6E+07	9.2E+02	1.8E-05	8.9E-07	9.2E+02
Pu-239	1.7E-05	5.3E-13	5.3E-13	5.6E+07	7.1E+01	1.6E-05	6.0E-08	7.1E+01
Pu-240	3.0E-05	9.6E-13	9.6E-13	5.6E+07	1.3E+02	1.8E-05	1.2E-07	1.3E+02
Am-241	1.9E-04	5.9E-12	5.9E-12	1.4E+08	2.1E+03	3.0E-03	1.3E-04	2.1E+03
Pu-241	2.3E-03	7.4E-11	7.4E-11	5.9E+05	1.1E+02	2.7E-07	1.4E-07	1.1E+02
Am-243	2.1E-06	6.6E-14	6.6E-14	1.4E+08	2.3E+01	8.1E-03	3.8E-06	2.3E+01
Cm-243	9.8E-07	3.1E-14	3.1E-14	1.1E+08	8.0E+00	2.2E-02	4.8E-06	8.0E+00
Cm-244	1.3E-04	4.1E-12	4.1E-12	9.3E+07	9.1E+02	1.8E-05	5.3E-07	9.1E+02
Total Sum	1.2E+04	3.7E-04	--	--	1.6E+04	--	1.1E+03	1.7E+04

Notes: (1) Table 9, column (1)

(2) Table 9, column (8)

(3) (2) / 3,600 s/hr / 24 hr/d / 365 d/yr

(4) (3) × 1.0 s/m^3 (unit χ/Q)

(5) ICRP 1995, Tables B.1& C.1 [a unit conversion factor of 3.7×10^{12} (rem/Ci)/(Sv/Bq)]
Dose factors for H-3 and C-14 are based on tritiated water and carbon dioxide (Maximum dose factors from organically bound elements are not applicable to SNF).

(6) Equation 6 (with T = 2,000 hours/yr, Assumption 4.3.7): (4) × (5) × 3.33×10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(7) Table 10a, column (7)

(8) (4) (Ci/m^3) × (7) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(9) (6) + (8).

Table 11a. Worker TODE, SDE and LDE Calculation (1500 MTHM/yr Throughput, FGR-11 Dose Factors, χ/Q = 1)

Nuclide	Receptor Concentration	DCF Organ	Organ Dose (CDE)	Organ Dose (TODE)	Skin Dose Factor	Skin Dose (SDE)	Lens Dose (LDE)
	Ci/m^3	rem/Ci	mrem/year	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H-3	3.4E-05	6.4E+01	5.3E+03	5.3E+03	0.0E+00	0.0E+00	5.3E+03
C-14	1.0E-07	2.4E+01	5.6E+00	5.6E+00	9.0E-04	6.5E-01	6.3E+00
Cl-36	2.0E-09	1.9E+03	9.1E+00	9.1E+00	5.4E-02	8.0E-01	1.1E+02
Kr-85	3.4E-04	0.0E+00	0.0E+00	1.1E+03	4.9E-02	1.2E+05	1.2E+05
I-129	6.6E-09	5.1E+02	8.1E+00	8.2E+00	4.1E-03	1.9E-01	2.8E+03
Cs-137	8.2E-10	2.9E+04	5.8E+01	5.9E+01	1.6E-01	9.6E-01	6.5E+01
Crud Co-60	3.5E-10	5.0E+04	4.2E+01	4.3E+01	5.4E-01	1.4E+00	1.9E+02
Fuel Co-60	9.4E-13	5.0E+04	1.1E-01	1.2E-01	5.4E-01	3.6E-03	5.0E-01
Ni-63	7.6E-13	6.3E+03	1.1E-02	1.1E-02	0.0E+00	0.0E+00	4.2E-03
Sr-90	8.2E-11	2.7E+06	5.3E+02	5.3E+02	2.6E-01	1.6E-01	2.5E+02
Pm-147	3.6E-13	3.8E+05	3.2E-01	3.2E-01	3.0E-03	7.7E-06	3.4E-02
Sm-151	6.3E-13	5.1E+05	7.8E-01	7.8E-01	7.0E-07	3.2E-09	4.6E-02
Eu-154	2.0E-12	1.9E+06	9.4E+00	9.4E+00	3.1E-01	4.5E-03	1.4E+00
Pu-238	6.9E-12	2.7E+09	4.4E+04	4.4E+04	1.5E-04	7.5E-06	4.8E+03
Pu-239	5.3E-13	3.0E+09	3.9E+03	3.9E+03	6.9E-05	2.6E-07	3.9E+02
Pu-240	9.6E-13	3.0E+09	7.0E+03	7.0E+03	1.5E-04	1.0E-06	7.1E+02
Am-241	5.9E-12	8.0E+09	1.1E+05	1.1E+05	4.7E-03	2.0E-04	6.3E+03
Pu-241	7.4E-11	6.6E+07	1.2E+04	1.2E+04	4.3E-07	2.3E-07	8.8E+02
Am-243	6.6E-14	8.0E+09	1.3E+03	1.3E+03	1.0E-02	4.8E-06	7.0E+01
Cm-243	3.1E-14	5.4E+09	4.0E+02	4.0E+02	3.6E-02	8.1E-06	2.3E+01
Cm-244	4.1E-12	4.3E+09	4.2E+04	4.2E+04	1.4E-04	4.3E-06	2.4E+03
Total Sum	3.7E-04	--	2.3E+05	2.3E+05	--	1.2E+05	1.4E+05

Notes:
(1) Table 10a, column (1)
(2) Table 10a, column (4)
(3) Table IV-1a, Bone Surface
(4) Equation 6 (with T=2,000 hr/yr, Assumption 4.3.7): (2) × (3) × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem
(5) (4) + Table 10a, column (8)
(6) Eckerman and Ryman 1993, Table III.1 [applying a unit conversion factor of 3.7 × 10^{12} (rem/Ci)/(Sv/Bq)]
(7) (2) (Ci/m^3) × (6) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem
(8) (7) + Table 10a, column (9).
CDE = committed dose equivalent.

Table 11b. Worker TODE, SDE and LDE Calculation (1500 MTHM/yr Throughput, ICRP-68 Dose Factors, χ/Q = 1)

Nuclide	Receptor Concentration	DCF Organ	Organ Dose (CDE)	Organ Dose (TODE)	Skin Dose Factor	Skin Dose (SDE)	Lens Dose (LDE)
	Ci/m^3	rem/Ci	mrem/year	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H-3	3.4E-05	6.7E+01	5.5E+03	5.5E+03	0.0E+00	0.0E+00	5.5E+03
C-14	1.0E-07	2.4E+01	5.8E+00	5.8E+00	9.0E-04	6.5E-01	6.4E+00
Cl-36	2.0E-09	1.0E+03	5.1E+00	5.1E+00	5.4E-02	8.0E-01	1.3E+02
Kr-85	3.4E-04	0.0E+00	0.0E+00	1.1E+03	4.9E-02	1.2E+05	1.2E+05
I-129	6.6E-09	1.4E+03	2.2E+01	2.2E+01	4.1E-03	1.9E-01	5.6E+03
Cs-137	8.2E-10	2.4E+04	4.8E+01	4.9E+01	1.6E-01	9.6E-01	5.1E+01
Crud Co-60	3.5E-10	3.3E+04	2.8E+01	2.9E+01	5.4E-01	1.4E+00	9.3E+01
Fuel Co-60	9.4E-13	3.3E+04	7.3E-02	7.7E-02	5.4E-01	3.6E-03	2.5E-01
Ni-63	7.6E-13	6.3E+03	1.1E-02	1.1E-02	0.0E+00	0.0E+00	1.3E-02
Sr-90	8.2E-11	6.7E+04	1.3E+01	1.3E+01	2.6E-01	1.6E-01	1.1E+02
Pm-147	3.6E-13	2.7E+05	2.3E-01	2.3E-01	3.0E-03	7.7E-06	1.5E-02
Sm-151	6.3E-13	3.7E+05	5.6E-01	5.6E-01	7.0E-07	3.2E-09	2.1E-02
Eu-154	2.0E-12	1.4E+06	7.0E+00	7.0E+00	3.1E-01	4.5E-03	9.0E-01
Pu-238	6.9E-12	5.6E+08	9.2E+03	9.2E+03	1.5E-04	7.5E-06	9.2E+02
Pu-239	5.3E-13	6.3E+08	8.0E+02	8.0E+02	6.9E-05	2.6E-07	7.1E+01
Pu-240	9.6E-13	6.3E+08	1.4E+03	1.4E+03	1.5E-04	1.0E-06	1.3E+02
Am-241	5.9E-12	5.9E+09	8.5E+04	8.5E+04	4.7E-03	2.0E-04	2.1E+03
Pu-241	7.4E-11	1.4E+07	2.5E+03	2.5E+03	4.3E-07	2.3E-07	1.1E+02
Am-243	6.6E-14	5.9E+09	9.4E+02	9.4E+02	1.0E-02	4.8E-06	2.3E+01
Cm-243	3.1E-14	4.1E+09	3.0E+02	3.0E+02	3.6E-02	8.1E-06	8.0E+00
Cm-244	4.1E-12	3.2E+09	3.2E+04	3.2E+04	1.4E-04	4.3E-06	9.1E+02
Total Sum	3.7E-04	--	1.4E+05	1.4E+05	--	1.2E+05	1.4E+05

Notes:
(1) Table 10b, column (1)
(2) Table 10b, column (4)
(3) Bone Surface, ICRP 1999 [applying a unit conversion factor of 3.7×10^{12} (rem/Ci)/(Sv/Bq)]
(4) Equation 6 (with T=2,000 hr/yr, Assumption 4.3.7): (2) × (3) × 3.33×10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem
(5) (4) + Table 10b, column (8)
(6) Table 11a, column (6)
(7) (2) (Ci/m^3) × (6) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem
(8) (7) + Table 10b, column (9).
CDE = committed dose equivalent.

Table 12a. Surface Facility Annual Release Maximum Worker Dose Calculation (FGR-11 Dose Factors)

Release Facility (1)	**χ/Q (2)**	**Total Dose (TEDE) (3)**	**Organ Dose (TODE) (4)**	**Skin Dose (SDE) (5)**	**Lens Dose (LDE) (6)**
	s/m^3	**mrem/year**	**mrem/year**	**mrem/year**	**mrem/year**
1500 MTHM/yr (A)	1.0	2.5E+04	2.3E+05	1.2E+05	1.4E+05
FHF (B)	2.8E-05	2.8E-01	2.6E+00	1.3E+00	1.6E+00
DTF 1 (C)	4.7E-05	1.2E+00	1.1E+01	5.6E+00	6.8E+00
DTF 2 (D)	1.8E-05	4.6E-01	4.2E+00	2.1E+00	2.6E+00

Notes: FHF = Fuel Handling Facility, DTF 1 = Dry Transfer Facility 1, DTF 2 = Dry Transfer Facility 2.

(A): (2) χ/Q=1, (3) Table 10a, column 10, last row,
(A): (4)(5)(6) Table 11a last row
(B): (2) Table 1, FHF
(B): (3)(4)(5)(6): (B)(2) × (A) (3)(4)(5)(6) × 600(MTHM)/1500(MTHM)(Section 4.1.3)
(C): (2) Table 1, DTF1
(C): (3)(4)(5)(6): (C)(2) × (A) (3)(4)(5)(6)
(D): (2) Table 1, DTF2
(D): (3)(4)(5)(6): (D)(2) × (A) (3)(4)(5)(6)

Table 12b. Surface Facility Annual Release Maximum Worker Dose Calculation (ICRP-68 Dose Factors)

Release Facility (1)	**χ/Q (2)**	**Total Dose (TEDE) (3)**	**Organ Dose (TODE) (4)**	**Skin Dose (SDE) (5)**	**Lens Dose (LDE) (6)**
	s/m^3	**mrem/year**	**mrem/year**	**mrem/year**	**mrem/year**
1500 MTHM/yr (A)	1.0	1.7E+04	1.4E+05	1.2E+05	1.4E+05
FHF (B)	2.8E-05	1.9E-01	1.5E+00	1.3E+00	1.5E+00
DTF 1 (C)	4.7E-05	7.9E-01	6.5E+00	5.6E+00	6.4E+00
DTF 2 (D)	1.8E-05	3.0E-01	2.5E+00	2.1E+00	2.5E+00

Notes: FHF = Fuel Handling Facility, DTF 1 = Dry Transfer Facility 1, DTF 2 = Dry Transfer Facility 2.

(A): (2) χ/Q=1, (3) Table 10b, column 10, last row,
(A): (4)(5)(6) Table 11b last row
(B): (2) Table 1, FHF
(B): (3)(4)(5)(6): (B)(2) × (A) (3)(4)(5)(6) × 600(MTHM)/1500(MTHM)(Section 4.1.3)
(C): (2) Table 1, DTF1
(C): (3)(4)(5)(6): (C)(2) × (A) (3)(4)(5)(6)
(D): (2) Table 1, DTF2
(D): (3)(4)(5)(6): (D)(2) × (A) (3)(4)(5)(6)

6.2 SUBSURFACE FACILITY RELEASE CALCULATION

Potential airborne effluents from subsurface facilities under normal operations are the radionuclides generated by neutron activation of air and host rocks, and the contamination suspended from emplaced waste packages. Airborne radionuclide release rates and worker doses are calculated using the equations described in Section 3 and input parameters and assumptions detailed in Sections 4.2 and 4.4. For dose calculations, N-16 is ignored because, with a very short half-life of 7.13 second, it would decay to a negligible amount. For dose calculations, all released or suspended radioactive particles are assumed to be respirable (Assumption 4.4.3).

6.2.1 Waste Package Contamination Release

The equation used to calculate potential airborne release rate in Ci/yr from exhaust shafts due to resuspension of surface contamination on waste packages is Equation 2 of Section 3.2.1:

Detailed release calculations are provided in Attachment II. The calculation results of the radionuclide release rates are summarized in Table 13.

6.2.2 Neutron Activation Product Release

The equations used to calculate the activation product release rates are Equations 3, 4, and 5 as described in Section 3.2. Detailed release rate calculations are provided in Attachment III.

The results of the estimated releases from the subsurface facilities, due to normal operations, are summarized in Table 13.

Table 13. Subsurface Normal Operation Annual Release

Waste Package Surface Contamination[a]	
Radionuclide	Ci/yr
Cs-137	6.8E-03
Crud Co-60	2.9E-03
Co-60	7.8E-06
Ni-63	6.3E-06
Sr-90	6.8E-04
Y-90	6.8E-04
Pm-147	3.0E-06
Sm-151	5.3E-06
Eu-154	1.7E-05
Pu-241	6.2E-04
Pu-238	5.7E-05
Pu-239	4.4E-06
Pu-240	7.9E-06
Am-241	4.9E-05
Am-243	5.5E-07
Cm-243	2.6E-07
Cm-244	3.4E-05
Activated Air[b]	
N-16	3.4E-02
Ar-41	2.0E+01
Activated Dust[c]	
N-16	9.5E-13
Na-24	3.7E-03
Al-28	1.6E-03
Si-31	5.2E-04
K-42	8.0E-04

Fe-55	8.2E-05

Source: [a] Attachment II, Table II-2.
[b] Attachment III, Table III-3.
[c] Attachment III, Table III-4.

6.2.3 Subsurface Release Dose Calculation

The maximum worker doses resulting from subsurface releases are calculated using the equations presented in Section 3.4.

The annual maximum dose to a repository worker is calculated based on the maximum chronic atmospheric dispersion factor of 1.5×10^{-5} s/m^3 (Table 6) estimated at intake shaft #1. The individual work is assumed to work full time (2,000 hr/yr; Assumption 4.4.4) at the repository access main that is taking air from intake shaft #1 (Section 4.2.9). Airborne radioactive contamination in the access main may result from re-entry of released material from the exhaust shafts.

The annual doses (mrem/yr) received by the maximally exposed subsurface worker are calculated in Tables 14a (FGR-11 dose factors) and 14b (ICRP-68 dose factors) for TEDE and Tables 15a (FGR-11 dose factors) and 15b (ICRP-68 dose factors) for TODE, SDE and LDE.

The annual TEDE that could be received by a hypothetical individual who would stay in the immediate vicinity of the repository exhaust for 2000 hours/yr is also calculated to provide an estimate of the ultimate potential dose. The annual TEDE based on 2000 hours/yr exposure time is 16 (FGR-11) or 6.7 (ICRP-68) mrem/yr [0.080 (FGR-11) or 0.034 (ICRP-68) $\div 1.5 \times 10^{-5}$ s/m^3 $\div$ 340 m^3/s].

Table 14a. Worker TEDE Calculation from Subsurface Release (FGR-11 Dose Factors)

(1) Nuclide	(2) Annual Release	(3) Release Rate	(4) Receptor Concentration	(5) DCF Effective	(6) Inhalation Dose (CEDE)	(7) Submersion Dose Factor	(8) Submersion Dose (DDE)	(9) Total Dose (TEDE)
Waste Package Contamination	Ci/yr	Ci/s	Ci/m^3	Rem/Ci	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/year
Cs-137	6.8E-03	2.2E-10	3.3E-15	3.2E+04	2.5E-04	1.0E-01	2.4E-06	2.5E-04
Crud Co-60	2.9E-03	9.3E-11	1.4E-15	2.2E+05	7.3E-04	4.7E-01	4.7E-06	7.4E-04
Co-60	7.8E-06	2.5E-13	3.7E-18	2.2E+05	2.0E-06	4.7E-01	1.2E-08	2.0E-06
Ni-63	6.3E-06	2.0E-13	3.0E-18	6.3E+03	4.5E-08	0.0E+00	0.0E+00	4.5E-08
Sr-90	6.8E-04	2.2E-11	3.2E-16	1.3E+06	1.0E-03	7.3E-04	1.7E-09	1.0E-03
Pm-147	3.0E-06	9.4E-14	1.4E-18	3.9E+04	1.3E-07	2.6E-06	2.6E-14	1.3E-07
Sm-151	5.3E-06	1.7E-13	2.5E-18	3.0E+04	1.8E-07	1.3E-07	2.4E-15	1.8E-07
Eu-154	1.7E-05	5.3E-13	8.0E-18	2.9E+05	5.5E-06	2.3E-01	1.3E-08	5.5E-06
Pu-241	6.2E-04	2.0E-11	2.9E-16	5.0E+06	3.5E-03	2.7E-07	5.7E-13	3.5E-03
Pu-238	5.7E-05	1.8E-12	2.7E-17	2.9E+08	1.9E-02	1.8E-05	3.5E-12	1.9E-02
Pu-239	4.4E-06	1.4E-13	2.1E-18	3.1E+08	1.6E-03	1.6E-05	2.4E-13	1.6E-03
Pu-240	7.9E-06	2.5E-13	3.8E-18	3.1E+08	2.8E-03	1.8E-05	4.8E-13	2.8E-03
Am-241	4.9E-05	1.6E-12	2.4E-17	4.4E+08	2.5E-02	3.0E-03	5.1E-10	2.5E-02
Am-243	5.5E-07	1.7E-14	2.6E-19	4.4E+08	2.8E-04	8.1E-03	1.5E-11	2.8E-04
Cm-243	2.6E-07	8.2E-15	1.2E-19	3.1E+08	9.0E-05	2.2E-02	1.9E-11	9.0E-05
Cm-244	3.4E-05	1.1E-12	1.6E-17	2.5E+08	9.6E-03	1.8E-05	2.1E-12	9.6E-03
Sum of WP Contamination	--	--	--	--	6.4E-02	--	7.1E-06	6.4E-02
Air Activation								
N-16	3.4E-02	1.1E-09	1.6E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	2.0E+01	6.4E-07	9.6E-12	0.0E+00	0.0E+00	2.4E-01	1.7E-02	1.7E-02
Dust Activation								
N-16	9.5E-13	3.0E-20	4.5E-25	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	3.7E-03	1.2E-10	1.8E-15	1.2E+03	5.1E-06	8.1E-01	1.0E-05	1.5E-05
Al-28	1.6E-03	5.1E-11	7.6E-16	0.0E+00	0.0E+00	3.4E-01	1.9E-06	1.9E-06
Si-31	5.2E-04	1.7E-11	2.5E-16	2.2E+02	1.3E-07	4.3E-04	7.8E-10	1.3E-07
K-42	8.0E-04	2.5E-11	3.8E-16	1.4E+03	1.2E-06	5.4E-02	1.5E-07	1.4E-06
Fe-55	8.2E-05	2.6E-12	3.9E-17	2.7E+03	2.5E-07	0.0E+00	0.0E+00	2.5E-07
Sum of Activation	--	--	--	--	6.7E-06	--	1.7E-02	1.7E-02
Total Sum	--	--	--	--	6.4E-02	--	1.7E-02	8.0E-02

Notes: (1) (2) Table 13, columns (1 and 2)

(3) (2) / 3,600 s/hr / 24 hr/d / 365 d/yr

(4) (3) × 1.5 × 10^{-5} s/m^3 (maximum χ/Q, Table 6)

(5) Eckerman et al. 1988, Table 2.1 [applying a unit conversion factor of 3.7 × 10^{12} (rem/Ci)/(Sv/Bq)]

(6) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): (4) × (5) × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(7) Eckerman and Ryman 1993, Table III.1 (values have been applied by a unit conversion factor of 3.7 × 10^{12})

(8) (4) (Ci/m^3) × (7) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(9) (6) + (8).

Table 14b. Worker TEDE Calculation from Subsurface Release (ICRP-68 Dose Factors)

(1) Nuclide	(2) Annual Release	(3) Release Rate	(4) Receptor Concentration	(5) DCF Effective	(6) Inhalation Dose (CEDE)	(7) Submersion Dose Factor	(8) Submersion Dose (DDE)	(9) Total Dose (TEDE)
Waste Package Contamination	Ci/yr	Ci/s	Ci/m^3	Rem/Ci	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/year
Cs-137	6.8E-03	2.2E-10	3.3E-15	2.5E+04	1.9E-04	1.0E-01	2.4E-06	2.0E-04
Crud Co-60	2.9E-03	9.3E-11	1.4E-15	1.1E+05	3.6E-04	4.7E-01	4.7E-06	3.6E-04
Co-60	7.8E-06	2.5E-13	3.7E-18	1.1E+05	9.6E-07	4.7E-01	1.2E-08	9.7E-07
Ni-63	6.3E-06	2.0E-13	3.0E-18	7.4E+03	5.3E-08	0.0E+00	0.0E+00	5.3E-08
Sr-90	6.8E-04	2.2E-11	3.2E-16	5.6E+05	4.4E-04	7.3E-04	1.7E-09	4.4E-04
Pm-147	3.0E-06	9.4E-14	1.4E-18	1.7E+04	5.9E-08	2.6E-06	2.6E-14	5.9E-08
Sm-151	5.3E-06	1.7E-13	2.5E-18	1.4E+04	8.2E-08	1.3E-07	2.4E-15	8.2E-08
Eu-154	1.7E-05	5.3E-13	8.0E-18	1.9E+05	3.5E-06	2.3E-01	1.3E-08	3.6E-06
Pu-241	6.2E-04	2.0E-11	2.9E-16	5.9E+05	4.2E-04	2.7E-07	5.7E-13	4.2E-04
Pu-238	5.7E-05	1.8E-12	2.7E-17	5.6E+07	3.6E-03	1.8E-05	3.5E-12	3.6E-03
Pu-239	4.4E-06	1.4E-13	2.1E-18	5.6E+07	2.8E-04	1.6E-05	2.4E-13	2.8E-04
Pu-240	7.9E-06	2.5E-13	3.8E-18	5.6E+07	5.0E-04	1.8E-05	4.8E-13	5.0E-04
Am-241	4.9E-05	1.6E-12	2.4E-17	1.4E+08	8.1E-03	3.0E-03	5.1E-10	8.1E-03
Am-243	5.5E-07	1.7E-14	2.6E-19	1.4E+08	9.0E-05	8.1E-03	1.5E-11	9.0E-05
Cm-243	2.6E-07	8.2E-15	1.2E-19	1.1E+08	3.1E-05	2.2E-02	1.9E-11	3.1E-05
Cm-244	3.4E-05	1.1E-12	1.6E-17	9.3E+07	3.6E-03	1.8E-05	2.1E-12	3.6E-03
Sum of WP Contamination					1.8E-02		7.1E-06	1.8E-02
Air Activation								
N-16	3.4E-02	1.1E-09	1.6E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	2.0E+01	6.4E-07	9.6E-12	0.0E+00	0.0E+00	2.4E-01	1.7E-02	1.7E-02
Dust Activation								
N-16	9.5E-13	3.0E-20	4.5E-25	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	3.7E-03	1.2E-10	1.8E-15	2.0E+03	8.3E-06	8.1E-01	1.0E-05	1.8E-05
Al-28	1.6E-03	5.1E-11	7.6E-16	0.0E+00	0.0E+00	3.4E-01	1.9E-06	1.9E-06
Si-31	5.2E-04	1.7E-11	2.5E-16	4.1E+02	2.4E-07	4.3E-04	7.8E-10	2.4E-07
K-42	8.0E-04	2.5E-11	3.8E-16	7.4E+02	6.7E-07	5.4E-02	1.5E-07	8.2E-07
Fe-55	8.2E-05	2.6E-12	3.9E-17	3.4E+03	3.2E-07	0.0E+00	0.0E+00	3.2E-07
Sum of Air and Dust Activation	--	--	--	--	9.5E-06	--	1.7E-02	1.7E-02
Total Sum	--	--	--	--	1.8E-02	--	1.7E-02	3.4E-02

Notes: (1) (2) Table 13, columns (1 and 2)

(3) (2) / 3,600 s/hr / 24 hr/d / 365 d/yr

(4) (3) × 1.5 × 10^{-5} s/m^3 (maximum χ/Q, Table 6)

(5) ICRP 1995, Tables B.1& C.1 [a unit conversion factor of 3.7x10^{12} (rem/Ci)/(Sv/Bq)]

(6) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): (4) × (5) × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(7) Table 14a, column (7)

(8) (4) (Ci/m^3) × (7) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(9) (6) + (8).

Table 15a. Worker TODE, SDE and LDE Calculation from Subsurface Release (FGR-11 Dose Factors)

Nuclide	Receptor Concentration	DCF Bone Surface	Organ Dose (CDE)	Organ Dose (TODE)	Skin Dose Factor	Skin Dose (SDE)	Lens Dose (LDE)
	Ci/m^3	rem/Ci	mrem/year	mrem/year	(rem/s)/(Ci/m^3)	mrem/year	mrem/year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Waste Package							
Cs-137	3.3E-15	2.9E+04	2.3E-04	2.3E-04	1.6E-01	3.8E-06	2.6E-04
Crud Co-60	1.4E-15	5.0E+04	1.7E-04	1.7E-04	5.4E-01	5.4E-06	7.4E-04
Co-60	3.7E-18	5.0E+04	4.5E-07	4.6E-07	5.4E-01	1.4E-08	2.0E-06
Ni-63	3.0E-18	6.3E+03	4.5E-08	4.5E-08	0.0E+00	0.0E+00	4.5E-08
Sr-90	3.2E-16	2.7E+06	2.1E-03	2.1E-03	2.6E-01	6.2E-07	1.0E-03
Pm-147	1.4E-18	3.8E+05	1.3E-06	1.3E-06	3.0E-03	3.1E-11	1.3E-07
Sm-151	2.5E-18	5.1E+05	3.1E-06	3.1E-06	7.0E-07	1.3E-14	1.8E-07
Eu-154	8.0E-18	1.9E+06	3.7E-05	3.7E-05	3.1E-01	1.8E-08	5.5E-06
Pu-241	2.9E-16	6.6E+07	4.6E-02	4.6E-02	4.3E-07	9.1E-13	3.5E-03
Pu-238	2.7E-17	2.7E+09	1.8E-01	1.8E-01	1.5E-04	3.0E-11	1.9E-02
Pu-239	2.1E-18	3.0E+09	1.5E-02	1.5E-02	6.9E-05	1.0E-12	1.6E-03
Pu-240	3.8E-18	3.0E+09	2.8E-02	2.8E-02	1.5E-04	3.9E-12	2.8E-03
Am-241	2.4E-17	8.0E+09	4.5E-01	4.5E-01	4.7E-03	8.0E-10	2.5E-02
Am-243	2.6E-19	8.0E+09	5.0E-03	5.0E-03	1.0E-02	1.9E-11	2.8E-04
Cm-243	1.2E-19	5.4E+09	1.6E-03	1.6E-03	3.6E-02	3.2E-11	9.0E-05
Cm-244	1.6E-17	4.3E+09	1.7E-01	1.7E-01	1.4E-04	1.7E-11	9.6E-03
Sum of Waste Package Contamination	--	--	8.9E-01	8.9E-01	--	9.8E-06	6.4E-02
Air Activation							
N-16	1.6E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	9.6E-12	0.0E+00	0.0E+00	1.7E-02	3.7E-01	2.6E-02	4.3E-02
Dust Activation							
N-16	4.5E-25	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	1.8E-15	9.5E+02	4.0E-06	1.4E-05	1.0E+00	1.3E-05	2.8E-05
Al-28	7.6E-16	0.0E+00	0.0E+00	1.9E-06	7.0E-01	3.8E-06	5.7E-06
Si-31	2.5E-16	2.7E-01	1.6E-10	9.4E-10	1.4E-01	2.5E-07	3.8E-07
K-42	3.8E-16	3.9E+02	3.6E-07	5.0E-07	4.3E-01	1.2E-06	2.5E-06
Fe-55	3.9E-17	1.9E+03	1.8E-07	1.8E-07	0.0E+00	0.0E+00	2.5E-07
Sum of Air and Dust Activation	--	--	4.6E-06	1.7E-02	--	2.6E-02	4.3E-02
Total Sum	--	--	8.9E-01	9.1E-01	--	2.6E-02	1.1E-01

Notes: (1) Table 14a, column (1)

(2) Table 14a, column (4)

(3) Table IV-2a, bone surface

(4) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): (2) × (3) × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(5) (4) + Table 14a, column (8)

(6) Eckerman and Ryman 1993, Table III.1 [applying a unit conversion factor of 3.7 × 10^{12} (rem/Ci)/(Sv/Bq)]

(7) (2) (Ci/m^3) × (6) (rem/s)/(Ci/m^3) × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(8) (7) + Table 14a, column (9)

CDE = committed dose equivalent.

Table 15b. Worker TODE, SDE and LDE Calculation from Subsurface Release (ICRP-68 Dose Factors)

Nuclide	Receptor Concentration	DCF Bone Surface	Organ Dose (CDE)	Organ Dose (TODE)	Skin Dose Factor	Skin Dose (SDE)	Lens Dose (LDE)
	Ci/m^3	rem/Ci	mrem/year	mrem/year	$(rem/s)/(Ci/m^3)$	mrem/year	mrem/year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Waste Package							
Cs-137	3.3E-15	2.4E+04	1.9E-04	1.9E-04	1.6E-01	3.8E-06	2.0E-04
Crud Co-60	1.4E-15	3.3E+04	1.1E-04	1.1E-04	5.4E-01	5.4E-06	3.7E-04
Co-60	3.7E-18	3.3E+04	2.9E-07	3.0E-07	5.4E-01	1.4E-08	9.8E-07
Ni-63	3.0E-18	6.3E+03	4.5E-08	4.5E-08	0.0E+00	0.0E+00	5.3E-08
Sr-90	3.2E-16	6.7E+04	5.2E-05	5.2E-05	2.6E-01	6.2E-07	4.4E-04
Pm-147	1.4E-18	2.7E+05	9.0E-07	9.0E-07	3.0E-03	3.1E-11	5.9E-08
Sm-151	2.5E-18	3.7E+05	2.2E-06	2.2E-06	7.0E-07	1.3E-14	8.2E-08
Eu-154	8.0E-18	1.4E+06	2.8E-05	2.8E-05	3.1E-01	1.8E-08	3.6E-06
Pu-241	2.9E-16	1.4E+07	9.9E-03	9.9E-03	4.3E-07	9.1E-13	4.2E-04
Pu-238	2.7E-17	5.6E+08	3.6E-02	3.6E-02	1.5E-04	3.0E-11	3.6E-03
Pu-239	2.1E-18	6.3E+08	3.2E-03	3.2E-03	6.9E-05	1.0E-12	2.8E-04
Pu-240	3.8E-18	6.3E+08	5.7E-03	5.7E-03	1.5E-04	3.9E-12	5.0E-04
Am-241	2.4E-17	5.9E+09	3.3E-01	3.3E-01	4.7E-03	8.0E-10	8.1E-03
Am-243	2.6E-19	5.9E+09	3.7E-03	3.7E-03	1.0E-02	1.9E-11	9.0E-05
Cm-243	1.2E-19	4.1E+09	1.2E-03	1.2E-03	3.6E-02	3.2E-11	3.1E-05
Cm-244	1.6E-17	3.2E+09	1.2E-01	1.2E-01	1.4E-04	1.7E-11	3.6E-03
Sum of Waste Package Contamination	--	--	5.2E-01	5.2E-01	--	9.8E-06	1.8E-02
Air Activation							
N-16	1.6E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	9.6E-12	0.0E+00	0.0E+00	1.7E-02	3.7E-01	2.6E-02	4.3E-02
Dust Activation							
N-16	4.5E-25	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	1.8E-15	1.6E+01	6.7E-08	1.0E-05	1.0E+00	1.3E-05	3.1E-05
Al-28	7.6E-16	0.0E+00	0.0E+00	1.9E-06	7.0E-01	3.8E-06	5.7E-06
Si-31	2.5E-16	1.9E+01	1.1E-08	1.2E-08	1.4E-01	2.5E-07	4.9E-07
K-42	3.8E-16	4.1E+02	3.7E-07	5.2E-07	4.3E-01	1.2E-06	2.0E-06
Fe-55	3.9E-17	6.7E+03	6.2E-07	6.2E-07	0.0E+00	0.0E+00	3.2E-07
Sum of Air and Dust Activation	--	--	1.1E-06	1.7E-02	--	2.6E-02	4.3E-02
Total Sum	--	--	5.2E-01	5.4E-01	--	2.6E-02	6.0E-02

Notes: (1) Table 14b, column (1)

(2) Table 14b, column (4)

(3) Bone Surface, ICRP 1999 [applying a unit conversion factor of 3.7×10^{12} (rem/Ci)/(Sv/Bq)]

(4) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): (2) × (3) × 3.33×10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem

(5) (4) + Table 14b, column (8)

(6) Table 15a, column (6)

(7) (2) (Ci/m^3) × (6) $(rem/s)/(Ci/m^3)$ × 2,000 hr/yr × 3,600 s/hr × 1,000 mrem/rem

(8) (7) + Table 14b, column (9)

CDE = committed dose equivalent.

7. RESULTS

To demonstrate that the potential releases from normal operations of the repository are within regulatory requirements, annual doses to the hypothetical maximally exposed worker are calculated based on the methods described in Section 3, applicable input parameters including assumptions in Sections 4, and calculations in Section 6.

Potential sources of airborne radioactive material releases were estimated for the surface repository under normal operations. They are releases from Fuel Handling Facility, Dry Transfer Facility 1 and Dry Transfer Facility 2. Three potential sources of airborne radioactive material releases were estimated for the subsurface repository under normal operations. They are radioactive contamination suspended from the external surfaces of the emplaced waste packages, neutron activation products generated from irradiation of ventilation air inside the emplacement drifts, and neutron activation products generated from irradiation of the host rocks inside the emplacement drifts.

The parameters used in the dose calculations are supported by appropriate data and conservative assumptions or are in accordance with appropriate NRC regulatory guides, standard review plans, and Interim Staff Guidance documents. The calculated doses to the maximally exposed worker are summarized in Table 16 for FHF, DTF1, DTF2 and Subsurface facilities. The maximum worker TEDEs are all less than 2 mrem/yr. The calculated results of maximum worker doses are reasonable compared to the inputs, and the results are suitable for the intended use. The uncertainties are taken into account by consistently using the conservative approach; the calculations, therefore, yield a conservatively bounding set of results. The dose calculations can be performed for all other receptors of concern by replacing the maximum χ/Q values with the appropriate χ/Q results presented in *GROA Airborne Release Dispersion Factor Calculation* (BSC 2005a, Tables 4, 5, and 17 for surface facility releases, and Tables 18 through 23 for subsurface facility releases).

Table 16. Maximum Worker Doses from Repository Facilities Releases

Release Facility (1)	**Source of Inhalation Dose Factor (2)**	**TEDE (mrem)** (3)	**TODE (mrem)** (4)	**SDE (mrem)** (5)	**LDE (mrem)** (6)
FHF	FGR-11	2.8E-01	2.6E+00	1.3E+00	1.6E+00
	ICRP-68	1.9E-01	1.5E+00	1.3E+00	1.5E+00
DTF1	FGR-11	1.2E+00	1.1E+01	5.6E+00	6.8E+00
	ICRP-68	7.9E-01	6.5E+00	5.6E+00	6.4E+00
DTF2	FGR-11	4.6E-01	4.2E+00	2.1E+00	2.6E+00
	ICRP-68	3.0E-01	2.5E+00	2.1E+00	2.5E+00
Subsurface	FGR-11	8.0E-02	9.1E-01	2.6E-02	1.1E-01
	ICRP-68	3.4E-02	5.4E-01	2.6E-02	6.0E-02

NOTES: Notes: FHF = Fuel Handling Facility, DTF 1 = Dry Transfer Facility 1, DTF 2 = Dry Transfer Facility 2.
(3): TEDE for FHF, DTF1 and DTF2: Table 12a (FGR-11) and 12b (ICRP-68)
(3): TEDE for Subsurface: Table 14a (FGR-11) and 14b (ICRP-68)
(4): TODE for FHF, DTF1 and DTF2: Table 12a (FGR-11) and 12b (ICRP-68)
(4): TODE for Subsurface: Table 15a (FGR-11) and 15b (ICRP-68)
(5): SDE for FHF, DTF1 and DTF2: Table 12a (FGR-11) and 12b (ICRP-68)
(5): SDE for Subsurface: Table 15a (FGR-11) and 15b (ICRP-68)
(6): LDE for FHF, DTF1 and DTF2: Table 12a (FGR-11) and 12b (ICRP-68)
(6): LDE for Subsurface: Table 15a (FGR-11) and 15b (ICRP-68)

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9. ATTACHMENTS

This calculation document includes four attachments as shown in Table 17.

Table 17. List of Attachments

Attachment Number	Description	Pages
I	Selection of Source Term Radionuclides	5
II	Waste Package Contamination Release Calculation	2
III	Subsurface Activation Product Release Rate Calculation	2
IV	Organ Dose Calculation	5

ATTACHMENT I—SELECTION OF SOURCE TERM RADIONUCLIDES

The source term radionuclides are based selection criteria described in Section 4.1.2. For confinement analysis, the source term, as a minimum, includes activity from Co-60 in crud, activity from iodine, other fission products that contribute greater than 0.1 percent of design basis fuel activity, and actinide activity that contributes greater than 0.01 percent of the design basis activity. Tables I-1 (PWR) and I-2 (BWR) present radionuclide activities and the contribution (percent) of the source term radionuclides. C-14 and Cl-36 are included because of potential releases to the atmosphere in gaseous form. The bolded cells represent the selected radionuclides that are included in release and dose calculations. As shown on Table I-3, these selected nuclides contribute more than 99.9% of the calculated total TEDE.

Table I-1. Radionuclide Source Term Selection for Pressurized Water Reactor Spent Nuclear Fuel

Nuclide[a]	Avg PWR Curies/FA[a]	Nuclide[a]	Avg PWR Curies/FA[a]
H-3[b]	1.14E+02	Eu-155	5.16E+01
C-14[d]	3.32E-01	Pb-210	0.00E+00
Cl-36[d]	6.80E-03	Ra-226	0.00E+00
Fe-55	3.47E+00	Ac-227	1.61E-05
Ni-59	2.09E+00	Ra-228	0.00E+00
Co-60[b]	3.13E+02	Th-229	0.00E+00
Ni-63[b]	2.52E+02	Th-230	1.48E-04
Se-79	4.57E-02	Pa-231	2.97E-05
Kr-85[b]	1.13E+03	Th-232	0.00E+00
Sr-90[b]	2.72E+04	U-232	2.05E-02
Y-90[e]	2.72E+04	U-233	4.07E-05
Nb-93m	1.30E+01	U-234	6.77E-01
Zr-93	8.94E-01	U-235	7.36E-03
Nb-94	8.39E-01	U-236	1.72E-01
Tc-99	8.99E+00	Np-237	2.47E-01
Ru-106	1.23E-02	**Pu-238[b]**	2.29E+03
Pd-107	8.41E-02	U-238	1.48E-01
Cd-113m	7.66E+00	**Pu-239[b]**	1.77E+02
Sb-125	9.71E+00	**Pu-240[b]**	3.18E+02
Sn-126	3.85E-01	**Am-241[b]**	1.98E+03
I-129[c]	2.20E-02	**Pu-241[b]**	2.47E+04
Cs-134	2.52E+01	Am-242m	6.39E+00
Cs-135	3.50E-01	Cm-242	5.27E+00
Cs-137[b]	4.11E+04	Pu-242	1.64E+00
Ba-137m[e]	3.88E+04	**Am-243[b]**	2.20E+01
Pm-147[b]	1.19E+02	**Cm-243[b]**	1.03E+01
Sm-147	0.00E+00	**Cm-244[b]**	1.36E+03
Sm-151[b]	2.11E+02	Cm-245	3.07E-01
Eu-154[b]	6.71E+02	Cm-246	1.04E-01

NOTES: [a]Source: (BSC 2004a, Attachment IX). FA = fuel assembly.

[b]Radionuclides selected per Section 4.1.2 are: Fission products: 0.1 % total activity; Actinides: 0.01 % total activity

[c]Iodine Section 4.1.2

[d]Section 4.1.2

[b,c,d] Bolded cells represent the selected radionuclides that are included in release calculations (Table 9)

[e]Y-90 and Ba-137m are included with Sr-90 and Cs-137, respectively, in dose calculations.

Table I-2. Radionuclide Source Term Selection for Boiling Water Reactor Spent Nuclear Fuel

Nuclide[a]	Avg BWR Curies/FA[a]	Nuclide[a]	Avg BWR Curies/FA[a]
H-3	3.95E+01	**Sm-151**[b]	5.39E+01
C-14 [d]	1.75E-01	**Eu-154**[b]	1.75E+02
Cl-36 [d]	2.93E-03	Eu-155	1.60E+01
Fe-55	1.09E+00	Ac-227	0.00E+00
Ni-59	5.02E-01	Th-230	6.09E-05
Co-60[b]	4.39E+01	Pa-231	1.39E-05
Ni-63[b]	5.86E+01	U-232	4.63E-03
Se-79	1.59E-02	U-233	1.06E-05
Kr-85	3.81E+02	U-234	2.50E-01
Sr-90[b]	9.54E+03	U-235	2.62E-03
Y-90[e]	9.54E+03	U-236	6.26E-02
Nb-93m	4.73E-01	Np-237	6.88E-02
Zr-93	3.39E-01	**Pu-238**[b]	5.85E+02
Nb-94	1.87E-02	U-238	6.32E-02
Tc-99	3.20E+00	**Pu-239**[b]	5.35E+01
Ru-106	3.00E-03	**Pu-240**[b]	1.14E+02
Pd-107	2.65E-02	**Am-241**[b]	5.58E+02
Cd-113m	2.26E+00	**Pu-241**[b]	6.78E+03
Sb-125	2.89E+00	Am-242m	2.17E+00
Sn-126	1.27E-01	Cm-242	1.78E+00
I-129 [c]	7.42E-03	Pu-242	5.08E-01
Cs-134	6.32E+00	**Am-243**[b]	5.34E+00
Cs-135	1.39E-01	**Cm-243**[b]	2.47E+00
Cs-137[b]	1.39E+04	**Cm-244**[b]	2.55E+02
Ba-137m[e]	1.31E+04	Cm-245	4.03E-02
Pm-147[b]	3.98E+01	Cm-246	1.45E-02

NOTES: [a] Source: (BSC 2003d, Attachment XIII).
FA = fuel assembly
Radionuclides selected are shown in bold text
[b] Radionuclides selected (bold face) per Section 4.1.2 are:
Fission products> 0.1 percent total activity; and actinides > 0.01 percent total activity.
[c] Iodine Section 4.1.2
[d] Section 4.1.2
[e] Y-90 and Ba-137m are included with Sr-90 and Cs-137, respectively, in dose calculations.

Table I-3. Dose Calculation to Determine Radionuclides of Radiological Significance

Nuclide	Source Term per FA	Annual Through-put	Failed FA Ci/yr	Gap Fraction	Release to Off-gas	leak path factor (LPF)	Release from Off-gas	Release Rate	Air Concen-tration	DCF Effective	Inhala-tion Dose (CEDE)	Submer-sion DCF	Subm. Dose (DDE)	Total Dose (TEDE)	Dose contributions	
Average PWR	Ci/FA	Ci/yr	1.0% Breaches for fuel nuclides	Table 8	Ci/yr		Ci/yr	Ci/s	Ci/m^3	rem/Ci	mrem/yr	(rem/s)/(Ci/m^3)	mrem/yr	mrem/yr	%	Cumula-tive %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Am-241	2.0E+03	6.3E+06	6.3E+04	3.0E-05	1.9E+00	1.0E-04	1.9E-04	5.9E-12	5.9E-12	4.4E+08	6.3E+03	3.0E-03	1.3E-04	6.3E+03	24.97%	25.0%
H-3	1.1E+02	3.6E+05	3.6E+03	3.0E-01	1.1E+03	1.0E+00	1.1E+03	3.4E-05	3.4E-05	6.4E+01	5.3E+03	1.2E-06	3.0E-01	5.3E+03	20.77%	45.7%
Pu-238	2.3E+03	7.2E+06	7.2E+04	3.0E-05	2.2E+00	1.0E-04	2.2E-04	6.9E-12	6.9E-12	2.9E+08	4.8E+03	1.8E-05	8.9E-07	4.8E+03	18.79%	64.5%
I-129	2.2E-02	6.9E+01	6.9E-01	3.0E-01	2.1E-01	1.0E+00	2.1E-01	6.6E-09	6.6E-09	1.7E+05	2.8E+03	1.4E-03	6.7E-02	2.8E+03	10.88%	75.4%
Cm-244	1.4E+03	4.3E+06	4.3E+04	3.0E-05	1.3E+00	1.0E-04	1.3E-04	4.1E-12	4.1E-12	2.5E+08	2.4E+03	1.8E-05	5.3E-07	2.4E+03	9.59%	85.0%
KR-85	1.1E+03	3.6E+06	3.6E+04	3.0E-01	1.1E+04	1.0E+00	1.1E+04	3.4E-04	3.4E-04	0.0E+00	0.0E+00	4.4E-04	1.1E+03	1.1E+03	4.25%	89.2%
Pu-241	2.5E+04	7.8E+07	7.8E+05	3.0E-05	2.3E+01	1.0E-04	2.3E-03	7.4E-11	7.4E-11	4.9E+06	8.8E+02	2.7E-07	1.4E-07	8.8E+02	3.48%	92.7%
Pu-240	3.2E+02	1.0E+06	1.0E+04	3.0E-05	3.0E-01	1.0E-04	3.0E-05	9.6E-13	9.6E-13	3.1E+08	7.1E+02	1.8E-05	1.2E-07	7.1E+02	2.79%	95.5%
Pu-239	1.8E+02	5.6E+05	5.6E+03	3.0E-05	1.7E-01	1.0E-04	1.7E-05	5.3E-13	5.3E-13	3.1E+08	3.9E+02	1.6E-05	6.0E-08	3.9E+02	1.55%	97.1%
Sr-90	2.7E+04	8.6E+07	8.6E+05	3.0E-05	2.6E+01	1.0E-04	2.6E-03	8.2E-11	8.2E-11	1.3E+06	2.5E+02	7.3E-04	4.3E-04	2.5E+02	1.01%	98.1%
Crud Co-60	2.3E+00	7.4E+03	7.4E+03	1.5E-02	1.1E+02	1.0E-04	1.1E-02	3.5E-10	3.5E-10	2.2E+05	1.9E+02	4.7E-01	1.2E+00	1.9E+02	0.74%	98.8%
Cl-36	6.8E-03	2.1E+01	2.1E-01	3.0E-01	6.4E-02	1.0E+00	6.4E-02	2.0E-09	2.0E-09	2.2E+04	1.1E+02	8.3E-05	1.2E-03	1.1E+02	0.42%	99.2%
Am-243	2.2E+01	6.9E+04	6.9E+02	3.0E-05	2.1E-02	1.0E-04	2.1E-06	6.6E-14	6.6E-14	4.4E+08	7.0E+01	8.1E-03	3.8E-06	7.0E+01	0.28%	99.5%
Cs-137	4.1E+04	1.3E+08	1.3E+06	2.0E-04	2.6E+02	1.0E-04	2.6E-02	8.2E-10	8.2E-10	3.2E+04	6.3E+01	1.0E-01	6.0E-01	6.4E+01	0.25%	99.8%
Cm-243	1.0E+01	3.3E+04	3.3E+02	3.0E-05	9.8E-03	1.0E-04	9.8E-07	3.1E-14	3.1E-14	3.1E+08	2.3E+01	2.2E-02	4.8E-06	2.3E+01	0.09%	99.8%
C-14	3.3E-01	1.0E+03	1.0E+01	3.0E-01	3.1E+00	1.0E+00	3.1E+00	1.0E-07	1.0E-07	2.4E+01	5.6E+00	8.3E-07	6.0E-04	5.6E+00	0.02%	99.9%
Eu-154	6.7E+02	2.1E+06	2.1E+04	3.0E-05	6.4E-01	1.0E-04	6.4E-05	2.0E-12	2.0E-12	2.9E+05	1.4E+00	2.3E-01	3.3E-03	1.4E+00	0.01%	99.9%
fuel Co-60	3.1E+02	9.9E+05	9.9E+03	3.0E-05	3.0E-01	1.0E-04	3.0E-05	9.4E-13	9.4E-13	2.2E+05	4.9E-01	4.7E-01	3.2E-03	5.0E-01	0.00%	99.9%
Sm-151	2.1E+02	6.7E+05	6.7E+03	3.0E-05	2.0E-01	1.0E-04	2.0E-05	6.3E-13	6.3E-13	3.0E+04	4.6E-02	1.3E-07	6.1E-10	4.6E-02	0.00%	99.9%
Pm-147	1.2E+02	3.8E+05	3.8E+03	3.0E-05	1.1E-01	1.0E-04	1.1E-05	3.6E-13	3.6E-13	3.9E+04	3.3E-02	2.6E-06	6.6E-09	3.3E-02	0.00%	99.9%
Ni-63	2.5E+02	8.0E+05	8.0E+03	3.0E-05	2.4E-01	1.0E-04	2.4E-05	7.6E-13	7.6E-13	2.3E+03	4.2E-03	0.0E+00	0.0E+00	4.2E-03	0.00%	99.9%
Above lists are Nuclides selected for dose calculations																
Am-242m	6.4E+00	2.0E+04	2.0E+02	3.0E-05	6.1E-03	1.0E-04	6.1E-07	1.9E-14	1.9E-14	4.3E+08	2.0E+01	1.2E-04	1.6E-08	2.0E+01	0.08%	100.0%
crud Fe-55	4.6E+00	1.5E+04	1.5E+04	1.5E-02	2.2E+02	1.0E-04	2.2E-02	7.0E-10	7.0E-10	2.7E+03	4.5E+00	0.0E+00	0.0E+00	4.5E+00	0.02%	100.0%
Pu-242	1.6E+00	5.2E+03	5.2E+01	3.0E-05	1.6E-03	1.0E-04	1.6E-07	4.9E-15	4.9E-15	2.9E+08	3.5E+00	1.5E-05	5.3E-10	3.5E+00	0.01%	100.0%
Cm-245	3.1E-01	9.7E+02	9.7E+00	3.0E-05	2.9E-04	1.0E-04	2.9E-08	9.2E-16	9.2E-16	4.6E+08	1.0E+00	1.5E-02	9.7E-08	1.0E+00	0.00%	100.0%
Np-237	2.5E-01	7.8E+02	7.8E+00	3.0E-05	2.3E-04	1.0E-04	2.3E-08	7.4E-16	7.4E-16	5.4E+08	9.6E-01	3.8E-03	2.0E-08	9.6E-01	0.00%	100.0%
Cm-242	5.3E+00	1.7E+04	1.7E+02	3.0E-05	5.0E-03	1.0E-04	5.0E-07	1.6E-14	1.6E-14	1.7E+07	6.6E-01	2.1E-05	2.4E-09	6.6E-01	0.00%	100.0%

U-234	6.8E-01	2.1E+03	2.1E+01	3.0E-05	6.4E-04	1.0E-04	6.4E-08	2.0E-15	2.0E-15	1.3E+08	6.5E-01	2.8E-05	4.1E-10	6.5E-01	0.00%	100.0%
Cm-246	1.0E-01	3.3E+02	3.3E+00	3.0E-05	9.9E-05	1.0E-04	9.9E-09	3.1E-16	3.1E-16	4.5E+08	3.4E-01	1.7E-05	3.7E-11	3.4E-01	0.00%	100.0%
U-236	1.7E-01	5.4E+02	5.4E+00	3.0E-05	1.6E-04	1.0E-04	1.6E-08	5.2E-16	5.2E-16	1.3E+08	1.6E-01	1.9E-05	6.9E-11	1.6E-01	0.00%	100.0%
U-238	1.5E-01	4.7E+02	4.7E+00	3.0E-05	1.4E-04	1.0E-04	1.4E-08	4.4E-16	4.4E-16	1.2E+08	1.3E-01	1.3E-05	4.0E-11	1.3E-01	0.00%	100.0%
U-232	2.1E-02	6.5E+01	6.5E-01	3.0E-05	1.9E-05	1.0E-04	1.9E-09	6.2E-17	6.2E-17	6.6E+08	9.7E-02	5.3E-05	2.3E-11	9.7E-02	0.00%	100.0%
Cd-113m	7.7E+00	2.4E+04	2.4E+02	3.0E-05	7.3E-03	1.0E-04	7.3E-07	2.3E-14	2.3E-14	1.5E+06	8.4E-02	2.6E-05	4.3E-09	8.4E-02	0.00%	100.0%
Eu-155	5.2E+01	1.6E+05	1.6E+03	3.0E-05	4.9E-02	1.0E-04	4.9E-06	1.6E-13	1.6E-13	4.1E+04	1.5E-02	9.2E-03	1.0E-05	1.5E-02	0.00%	100.0%
Cs-134	2.5E+01	8.0E+04	8.0E+02	3.0E-05	2.4E-02	1.0E-04	2.4E-06	7.6E-14	7.6E-14	4.6E+04	8.4E-03	2.8E-01	1.5E-04	8.6E-03	0.00%	100.0%
U-235	7.4E-03	2.3E+01	2.3E-01	3.0E-05	7.0E-06	1.0E-04	7.0E-10	2.2E-17	2.2E-17	1.2E+08	6.5E-03	2.7E-02	4.2E-09	6.5E-03	0.00%	100.0%
Nb-93m	1.3E+01	4.1E+04	4.1E+02	3.0E-05	1.2E-02	1.0E-04	1.2E-06	3.9E-14	3.9E-14	2.9E+04	2.7E-03	1.6E-05	4.6E-09	2.7E-03	0.00%	100.0%
Nb-94	8.4E-01	2.6E+03	2.6E+01	3.0E-05	7.9E-04	1.0E-04	7.9E-08	2.5E-15	2.5E-15	4.1E+05	2.5E-03	2.8E-01	5.2E-06	2.5E-03	0.00%	100.0%
Zr-93	8.9E-01	2.8E+03	2.8E+01	3.0E-05	8.5E-04	1.0E-04	8.5E-08	2.7E-15	2.7E-15	3.2E+05	2.1E-03	0.0E+00	0.0E+00	2.1E-03	0.00%	100.0%
Sb-125	9.7E+00	3.1E+04	3.1E+02	3.0E-05	9.2E-03	1.0E-04	9.2E-07	2.9E-14	2.9E-14	1.2E+04	8.5E-04	7.5E-02	1.6E-05	8.7E-04	0.00%	100.0%
Ac-227	1.6E-05	5.1E-02	5.1E-04	3.0E-05	1.5E-08	1.0E-04	1.5E-12	4.8E-20	4.8E-20	6.7E+09	7.8E-04	2.2E-05	7.5E-15	7.8E-04	0.00%	100.0%
Tc-99	9.0E+00	2.8E+04	2.8E+02	3.0E-05	8.5E-03	1.0E-04	8.5E-07	2.7E-14	2.7E-14	8.3E+03	5.4E-04	6.0E-06	1.2E-09	5.4E-04	0.00%	100.0%
Th-230	1.5E-04	4.7E-01	4.7E-03	3.0E-05	1.4E-07	1.0E-04	1.4E-11	4.4E-19	4.4E-19	3.3E+08	3.5E-04	6.4E-05	2.1E-13	3.5E-04	0.00%	100.0%
Sn-126	3.9E-01	1.2E+03	1.2E+01	3.0E-05	3.6E-04	1.0E-04	3.6E-08	1.2E-15	1.2E-15	1.0E+05	2.8E-04	7.8E-03	6.5E-08	2.8E-04	0.00%	100.0%
Pa-231	3.0E-05	9.4E-02	9.4E-04	3.0E-05	2.8E-08	1.0E-04	2.8E-12	8.9E-20	8.9E-20	1.3E+09	2.7E-04	6.4E-03	4.1E-12	2.7E-04	0.00%	100.0%
Fe-55	3.5E+00	1.1E+04	1.1E+02	3.0E-05	3.3E-03	1.0E-04	3.3E-07	1.0E-14	1.0E-14	2.7E+03	6.7E-05	0.0E+00	0.0E+00	6.7E-05	0.00%	100.0%
Ru-106	1.2E-02	3.9E+01	3.9E-01	3.0E-05	1.2E-05	1.0E-04	1.2E-09	3.7E-17	3.7E-17	4.8E+05	4.2E-05	0.0E+00	0.0E+00	4.2E-05	0.00%	100.0%
Ni-59	2.1E+00	6.6E+03	6.6E+01	3.0E-05	2.0E-03	1.0E-04	2.0E-07	6.3E-15	6.3E-15	2.7E+03	4.1E-05	0.0E+00	0.0E+00	4.1E-05	0.00%	100.0%
U-233	4.1E-05	1.3E-01	1.3E-03	3.0E-05	3.9E-08	1.0E-04	3.9E-12	1.2E-19	1.2E-19	1.4E+08	4.0E-05	6.0E-05	5.3E-14	4.0E-05	0.00%	100.0%
Cs-135	3.5E-01	1.1E+03	1.1E+01	3.0E-05	3.3E-04	1.0E-04	3.3E-08	1.1E-15	1.1E-15	4.6E+03	1.1E-05	2.1E-06	1.6E-11	1.1E-05	0.00%	100.0%
Pd-107	8.4E-02	2.7E+02	2.7E+00	3.0E-05	8.0E-05	1.0E-04	8.0E-09	2.5E-16	2.5E-16	1.3E+04	7.7E-06	0.0E+00	0.0E+00	7.7E-06	0.00%	100.0%
Se-79	4.6E-02	1.4E+02	1.4E+00	3.0E-05	4.3E-05	1.0E-04	4.3E-09	1.4E-16	1.4E-16	9.8E+03	3.2E-06	1.1E-06	1.1E-12	3.2E-06	0.00%	100.0%
Total	1.0E+05	3.2E+08	3.2E+06	--	1.2E+04	--	1.2E+04	3.7E-04	--	--	2.4E+04	--	1.1E+03	2.5E+04	100.0%	--

NOTES: (1) & (2) Source: Table I-1.

(3) (2) x 1500 (MTHM) / 0.475 (MTHM/FA); (Sections 4.1.1 and 4.1.3)
crud Co-60 2.3 Ci/FA (Assumption 4.3.1) x 1500 (MTHM) / 0.475 (MTHM/FA)
crud Fe-55 4.6 Ci/FA (Assumption 4.3.1) x 1500 (MTHM) / 0.475 (MTHM/FA).

(4) (3) x 0.01(Assumption 4.3.2 :1% failed)

(5) Source: Table 8.

(6) (4) x (5)

(7) Assumption 4.3.6

(8) (6) x (7)

(9) (8) / 3600 (s/hr) / 24 (hr/d) / 365 (d/yr)

(10) (9) x 1.0 (s/m^3) (unit χ/Q)

(11) Eckerman et al. 1988, Table 2.1 [applying a unit conversion factor of 3.7E12 (rem/Ci)/(Sv/Bq)]

(12) Equation 6 (with T=2000 hours/yr, Assumption 4.3.7): (10) x (11) x 3.33 x 10^{-4} (m^3/s) x 3600 (s/hr) x 2000 (hr/yr) x 1000 (mrem/rem)

(13) Eckerman and Ryman, 1993, Table III.1 [applying a unit conversion factor of 3.7E12 (rem/Ci)/(Sv/Bq)]

(14) (10) (Ci/m^3) x (13) (rem/s)/(Ci/m^3) x 2000 (hr/yr) x 3600 (s/hr) x 1000 (mrem/rem)

(15) (12) + (14)

(16) (15)/2.5E4 in %

(17) (16) + (16) of the row above

ATTACHMENT II—WASTE PACKAGE CONTAMINATION RELEASE

The resuspension release of the surface contamination from waste packages is calculated using Equation 2 (Section 3.2.1). The radionuclides selected are radiologically important according to *Recommended Surface Contamination Levels for Waste Packages Prior to Placement in the Repository* (Edwards and Yuan 2003, Appendix A). Input parameters for the release calculation are summarized in Table II-1. The release rate calculations are provided in Table II-2.

Table II-1. Waste Package Contamination Release Calculation Parameters

Parameter	Value	Source
Number of waste package emplaced per year, M	600	Assumption 4.4.1
Waste package surface area, A (m^2)	32	Section 4.2.6
Waste package contamination levels, C_s (Ci/m^2)	Beta/Gamma 9.5E-7	See below
	Alpha 8.0E-9	
	Total 9.6E-7	

Maximum waste package surface contamination prior to emplacement needs to satisfy equation II-1. That is:

$$F(\alpha) + F(\beta) = \frac{C(\alpha)}{G_\alpha} + \frac{C(\beta)}{G_\beta} = 1 \qquad \text{(Eq. II-1)}$$

or

$$\frac{C(\alpha)}{1.1 \times 10^{-8}} + \frac{C(\beta)}{3.4 \times 10^{-6}} = 1 \qquad \text{(Eq. II-2)}$$

where $F(\alpha)$ and $F(\beta)$ are the individual fractional recommended radioactive contamination levels of gross α and gross β/γ activities remaining on the waste package, respectively. $C(\alpha)$ and $C(\beta)$, respectively, are the average concentrations of gross α and gross β/γ activities on the waste package. G_α (1.1×10^{-8}) and G_β (3.4×10^{-6}), respectively, are the recommended radioactive contamination levels derived for the gross α and gross β/γ activities (see Table 3).

Radionuclide contamination distribution on the surfaces of waste packages is based on the particulate nuclides released from the processed waste materials (Table 9, column 6). Radioactive particulates suspended in the transfer cells are directly related to the radionuclides deposited on the waste packages. The values of $C(\alpha)$ and $C(\beta)$ are calculated in Table II-2 and are used to calculate the resuspension release of the surface contamination from waste packages.

$$\frac{C(\alpha)}{C(\beta)} = \frac{5.8}{690} = 0.0084 \qquad \text{(Eq. II-3)}$$

Solving equations II-2 and II-3, the results are:

$$C(\alpha) = 8.0 \times 10^{-9}\ Ci/m^2$$
$$C(\beta) = 9.5 \times 10^{-7}\ Ci/m^2$$

$$C(\alpha) + C(\beta) = 9.6 \times 10^{-7} \text{ Ci/m}^2.$$

The calculation of radionuclide release rates is shown in column (4) of Table II-2.

Table II-2. Waste Package Contamination Release Rate Calculation

Nuclide	Surface Facility Release Source Terms (Ci/yr)	Contamination Distribution (fraction)	Subsurface Annual Release Ci/yr
(1)	(2)	(3)	(4)
Beta-Gamma Emitting Nuclide			
Cs-137	2.6E+02	3.7E-01	6.8E-03
Ba-137m	2.4E+02	3.5E-01	6.4E-03
Crud Co-60	1.1E+02	1.6E-01	2.9E-03
Co-60	3.0E-01	4.3E-04	7.8E-06
Ni-63	2.4E-01	3.4E-04	6.3E-06
Sr-90	2.6E+01	3.7E-02	6.8E-04
Y-90	2.6E+01	3.7E-02	6.8E-04
Pm-147	1.1E-01	1.6E-04	3.0E-06
Sm-151	2.0E-01	2.9E-04	5.3E-06
Eu-154	6.4E-01	9.1E-04	1.7E-05
Pu-241	2.3E+01	3.4E-02	6.2E-04
Total beta-gamma	6.9E+02 (Used in Eq. II-3)	9.9E-01	1.8E-02
Alpha Emitting Nuclides			
Pu-238	2.2E+00	3.1E-03	5.7E-05
Pu-239	1.7E-01	2.4E-04	4.4E-06
Pu-240	3.0E-01	4.3E-04	7.9E-06
Am-241	1.9E+00	2.7E-03	4.9E-05
Am-243	2.1E-02	3.0E-05	5.5E-07
Cm-243	9.8E-03	1.4E-05	2.6E-07
Cm-244	1.3E+00	1.8E-03	3.4E-05
Total Alpha	5.8E+00 (Used in Eq. II-3)	8.4E-03	1.5E-04
Total Activity	7.0E+02	1.0E+00	1.8E-02

NOTES: (1) Source: Table A-3 (Edwards and Yuan 2003, Appendix A)
(2) Source: Table 9 (column 6)
(3) (2) / 7.0 × 10^2 (total Activity, column 2)
(4) (3) × 9.6 × 10^{-7} (total C_s) × 600 (M) × 32 (A) (Eq.2).

ATTACHMENT III—SUBSURFACE ACTIVATION PRODUCT RELEASE RATE

Equations 3, 4, and 5 (Section 3.2) are used to calculate the activation product release rates. The detailed release rate calculations are provided below. Table III-1 summarizes the input parameters used for activation product release calculations. Table III-2 presents the concentration calculation for activation products at the emplacement drift outlet. The release rate calculation for activation products in air for the six exhaust shafts is provided in Table III-3. Table III-4 presents the release rate calculation for dust activation products using Equation 4 (Section 3.2). For conservatism, the shortest travel time (33 seconds for exhaust raise #1) is used to account for radioactive decay during transit from the drift outlet to the shaft exhaust for dust release rate calculations.

Table III-1. Activation Product Release Calculation Parameters

Parameter	Value	Source
Air Activation Product Release Calculation Parameters		
Emplacement drift length, L (m)	600	Section 4.2.2
Emplacement drift area, A (m^2)	12.31	Section 4.2.3
Emplacement drift air volume, V (m^3)	7386	$V = L \times A$
Emplacement drift average airflow, U (m^3/s)	(15+17)/2 = 16	Section 4.2.1
Emplacement drift air irradiation time, Ti (s)	462	Ti = V / U
Drift to exhaust travel time, Te (s)	See Table 2	Section 4.2.4
Dust Activation Product Release Calculation Parameters		
Dust release rate (tons/yr)	250	Assumption 4.4.2
Decay time (shaft #1), Te (s)	33	Table 2, Section 4.2.4

Table III-2. Drift Outlet Air Activation Product Concentration Calculation

(1) Radionuclide in Air	(2) Half-life	(3) Decay Constant (1/s)	(4) Production Rate (1/cm^3-s)	(5) Concentration at Drift Exit (μCi/cm^3)
N-16	7.13 s	9.72E-02	3.32E-06	8.98E-11
Ar-41	1.83 hr	1.05E-04	2.71E-04	3.47E-10

NOTES: Source: (1), (2), and (4): Section 4.2.7 (Table 4).
(5) = (4) × (1-EXP(-(3) × Ti)) / 37,000. Ti = 462 (see Table III-1)

Table III-3. Shaft Exhaust Air Activation Product Concentration and Release Calculation

	Exhaust Raise #1	Exhaust Raise #2	Exhaust Shaft #1	Exhaust Shaft #2	Exhaust Shaft #3	ECRB Exhaust Shaft	Total
Concentration[c] (μCi/cm^3) Calculation							
Te [a] (s)	33	45	174	168	54	76	
N-16	3.63E-12	1.13E-12	4.06E-18	7.28E-18	4.72E-13	5.56E-14	
Ar-41	3.46E-10	3.45E-10	3.41E-10	3.41E-10	3.45E-10	3.44E-10	
Release[d] (Ci/yr) Calculation							
Airflow [b] (cms)	185	185	383	383	343	393	
N-16	2.12E-02	6.61E-03	4.91E-08	8.79E-08	5.11E-03	6.90E-04	3.36E-02
Ar-41	2.02E+00	2.01E+00	4.11E+00	4.12E+00	3.73E+00	4.27E+00	2.03E+01

NOTES: [a] Source: Table 2, Column 9, travel time
[b] Source: Table 2, Column 6, airflow
[c] Concentration = (5) from Table III-2 × EXP(-(3) from Table III-2 × Te)
[d] Release = Concentration (μCi/cm^3) 1.0×10^{-6} Ci/μCi × Airflow m^3/s × 1.0×10^6 cm^3/m^3 × 3,600 s/hr × 24 hr/day × 365 day/yr.
ECRB = enhanced characterization of the repository block (drift)

Table III-4. Shaft Exhaust Dust Activation Product Release Rate Calculation

Radionuclide in Dust	Half-life	Decay Constant (1/s)	Activity in Dust at Drift outlet (μCi/g)	Activity in Dust at Shaft Exit (μCi/g)	Release Ci/yr
(1)	(2)	(3)	(4)	(5)	(6)
N-16	7.13 s	9.72E-02	8.4E-08	3.8E-15	9.5E-13
Na-24	14.95 hr	1.29E-05	1.5E-05	1.5E-05	3.7E-03
Al-28	2.25 m	5.13E-03	1.6E-05	6.4E-06	1.6E-03
Si-31	2.62 hr	7.35E-05	2.1E-06	2.1E-06	5.2E-04
K-42	12.36 hr	1.56E-05	3.2E-06	3.2E-06	8.0E-04
Fe-55	2.73 yr	8.05E-09	3.3E-07	3.3E-07	8.2E-05

NOTES: Source: (1), (2), (4): Table 5, Section 4.2.8
(5) = (4) × EXP[-(3) × 174s (Te for shaft #1 from Table III-3)]
(6) = (5) (μCi/g) × 1.0×10^{-6} Ci/μCi × 1.0×10^6 g/ton × 250 tons/yr.

ATTACHMENT IV—ORGAN DOSE CALCULATION

Calculations of organ dose consequences (mrem) received by the maximally exposed worker are shown in Tables IV-1 and IV-2 for normal operational releases from DTF 1 and subsurface facility, respectively.

Table IV-1a. Dry Transfer Facility Release Worker Organ Dose Calculation (FGR-11 Dose Factors, Unit χ/Q)

Nuclide	DCF (a) Gonad	CDE (b) Gonad	DCF (a) Breast	CDE (b) Breast	DCF (a) Lung	CDE (b) Lung	DCF (a) R Marrow	CDE (b) R Marrow	DCF (a) Bone Surface	CDE (b) Bone Surface	DCF (a) Thyroid	CDE (b) Thyroid	DCF (a) Remainder	CDE (b) Remainder
	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem
H-3	6.4E+01	5.3E+03	6.4E+01	5.3E+03	6.4E+01	5.3E+03	6.4E+01	5.3E+03	6.4E+01	5.3E+03	6.4E+01	5.3E+03	6.4E+01	5.3E+03
C-14	2.4E+01	5.6E+00	2.4E+01	5.6E+00	2.4E+01	5.6E+00	2.4E+01	5.6E+00	2.4E+01	5.6E+00	2.4E+01	5.6E+00	2.4E+01	5.6E+00
Cl-36	1.9E+03	9.1E+00	1.9E+03	9.1E+00	1.7E+05	8.3E+02	1.9E+03	9.1E+00	1.9E+03	9.1E+00	1.9E+03	9.1E+00	2.0E+03	9.7E+00
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-129	3.2E+02	5.1E+00	7.7E+02	1.2E+01	1.2E+03	1.8E+01	5.2E+02	8.2E+00	5.1E+02	8.1E+00	5.8E+06	9.2E+04	4.4E+02	6.9E+00
Cs-137	3.2E+04	6.4E+01	2.9E+04	5.7E+01	3.3E+04	6.4E+01	3.1E+04	6.1E+01	2.9E+04	5.8E+01	2.9E+04	5.8E+01	3.4E+04	6.7E+01
Crud Co-60	1.8E+04	1.5E+01	6.8E+04	5.8E+01	1.3E+06	1.1E+03	6.4E+04	5.4E+01	5.0E+04	4.2E+01	6.0E+04	5.1E+01	1.3E+05	1.1E+02
Co-60	1.8E+04	4.0E-02	6.8E+04	1.5E-01	1.3E+06	2.9E+00	6.4E+04	1.4E-01	5.0E+04	1.1E-01	6.0E+04	1.4E-01	1.3E+05	3.0E-01
Ni-63	6.3E+03	1.1E-02	6.3E+03	1.1E-02	1.1E+04	2.1E-02	6.3E+03	1.1E-02	6.3E+03	1.1E-02	6.3E+03	1.1E-02	6.3E+03	1.1E-02
Sr-90	9.8E+03	1.9E+00	9.8E+03	1.9E+00	1.1E+07	2.1E+03	1.2E+06	2.4E+02	2.7E+06	5.3E+02	9.8E+03	1.9E+00	3.6E+04	7.0E+00
Pm-147	7.0E-02	6.0E-08	1.3E-01	1.1E-07	2.9E+05	2.5E-01	3.0E+04	2.6E-02	3.8E+05	3.2E-01	7.3E-02	6.3E-08	2.2E+04	1.9E-02
Sm-151	1.5E-01	2.3E-07	5.5E-01	8.4E-07	1.2E+04	1.8E-02	4.1E+04	6.2E-02	5.1E+05	7.8E-01	4.9E-02	7.4E-08	2.8E+04	4.2E-02
Eu-154	4.3E+04	2.1E-01	5.7E+04	2.8E-01	2.9E+05	1.4E+00	3.9E+05	1.9E+00	1.9E+06	9.4E+00	2.6E+04	1.3E-01	4.2E+05	2.0E+00
Pu-238	3.8E+07	6.4E+02	1.6E+03	2.7E-02	1.2E+09	2.0E+04	2.1E+08	3.5E+03	2.7E+09	4.4E+04	1.4E+03	2.4E-02	1.0E+08	1.7E+03
Pu-239	4.4E+07	5.7E+01	1.5E+03	1.9E-03	1.2E+09	1.5E+03	2.4E+08	3.1E+02	3.0E+09	3.9E+03	1.4E+03	1.8E-03	1.1E+08	1.4E+02
Pu-240	4.4E+07	1.0E+02	1.6E+03	3.7E-03	1.2E+09	2.7E+03	2.4E+08	5.6E+02	3.0E+09	7.0E+03	1.4E+03	3.2E-03	1.1E+08	2.6E+02
Am-241	1.2E+08	1.7E+03	9.9E+03	1.4E-01	6.8E+07	9.7E+02	6.4E+08	9.2E+03	8.0E+09	1.1E+05	5.9E+03	8.5E-02	2.9E+08	4.1E+03
Pu-241	1.0E+06	1.8E+02	7.9E+01	1.4E-02	1.2E+07	2.1E+03	5.3E+06	9.4E+02	6.6E+07	1.2E+04	3.4E+01	6.0E-03	2.2E+06	4.0E+02
Am-243	1.2E+08	1.9E+01	5.6E+04	8.9E-03	6.6E+07	1.0E+01	6.4E+08	1.0E+02	8.0E+09	1.3E+03	3.1E+04	4.9E-03	2.9E+08	4.5E+01
Cm-243	7.7E+07	5.7E+00	2.3E+04	1.7E-03	7.2E+07	5.3E+00	4.4E+08	3.2E+01	5.4E+09	4.0E+02	1.4E+04	1.1E-03	2.1E+08	1.6E+01
Cm-244	5.9E+07	5.8E+02	3.8E+03	3.8E-02	7.1E+07	7.0E+02	3.5E+08	3.4E+03	4.3E+09	4.2E+04	3.7E+03	3.7E-02	1.8E+08	1.7E+03
Total Sum	--	8.7E+03	--	5.4E+03	--	3.7E+04	--	2.4E+04	--	2.3E+05	--	9.7E+04	--	1.4E+04

Notes: [a] Eckerman et al. 1988, Table 2.1 [applying a unit conversion factor of 3.7×10^{12} (rem/Ci)/(Sv/Bq)]

[b] Equation 6: Table 11a (3) × DCF × 3.33×10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr (Assumption 4.3.7) × 1,000 mrem/rem

CDE = committed dose equivalent.

Table IV-1b. Dry Transfer Facility Release Worker Organ Dose Calculation (ICRP-68 Dose Factors, Unit χ/Q)

Nuclide	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)
	Gonad	Gonad	Breast	Breast	Lung	Lung	R Marrow	R Marrow	Bone Surface	Bone Surface	Thyroid	Thyroid	Remainder	Remainder
	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem
H-3	6.7E+01	5.5E+03	6.7E+01	5.5E+03	6.7E+01	5.5E+03	6.7E+01	5.5E+03	6.7E+01	5.5E+03	6.7E+01	5.5E+03	6.7E+01	5.5E+03
C-14	2.4E+01	5.8E+00	2.4E+01	5.8E+00	2.4E+01	5.8E+00	2.4E+01	5.8E+00	2.4E+01	5.8E+00	2.4E+01	5.8E+00	2.4E+01	5.8E+00
Cl-36	1.0E+03	5.1E+00	1.0E+03	5.1E+00	2.0E+05	1.0E+03	1.0E+03	5.1E+00	1.0E+03	5.1E+00	1.0E+03	5.1E+00	1.0E+03	5.1E+00
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-129	3.7E+02	5.9E+00	3.7E+02	5.9E+00	1.3E+03	2.1E+01	4.8E+02	7.6E+00	1.4E+03	2.2E+01	7.0E+06	1.1E+05	9.6E+02	1.5E+01
Cs-137	2.2E+04	4.4E+01	2.0E+04	3.9E+01	2.3E+04	4.5E+01	2.3E+04	4.6E+01	2.4E+04	4.8E+01	2.3E+04	4.6E+01	3.5E+04	6.9E+01
Crud Co-60	2.5E+03	2.1E+00	8.5E+04	7.2E+01	6.3E+05	5.3E+02	4.4E+04	3.8E+01	3.3E+04	2.8E+01	3.5E+04	2.9E+01	3.3E+04	2.8E+01
Co-60	2.5E+03	5.7E-03	8.5E+04	1.9E-01	6.3E+05	1.4E+00	4.4E+04	1.0E-01	3.3E+04	7.3E-02	3.5E+04	7.8E-02	3.3E+04	7.5E-02
Ni-63	6.3E+03	1.1E-02	6.3E+03	1.1E-02	1.0E+04	1.9E-02	6.3E+03	1.1E-02	6.3E+03	1.1E-02	6.3E+03	1.1E-02	1.4E+04	2.5E-02
Sr-90	1.2E+02	2.4E-02	1.2E+02	2.4E-02	4.5E+06	8.7E+02	3.0E+04	5.8E+00	6.7E+04	1.3E+01	1.2E+02	2.4E-02	3.3E+02	6.5E-02
Pm-147	1.4E+00	1.2E-06	1.4E+00	1.2E-06	6.7E+04	5.7E-02	2.1E+04	1.8E-02	2.7E+05	2.3E-01	1.4E+00	1.2E-06	1.0E+01	8.6E-06
Sm-151	4.8E-01	7.3E-07	5.9E-01	9.0E-07	1.0E+04	1.6E-02	3.0E+04	4.6E-02	3.7E+05	5.6E-01	5.2E-01	7.9E-07	3.0E+00	4.6E-06
Eu-154	1.1E+04	5.5E-02	4.1E+04	2.0E-01	3.5E+05	1.7E+00	3.2E+05	1.5E+00	1.4E+06	7.0E+00	2.6E+04	1.3E-01	4.4E+04	2.1E-01
Pu-238	7.4E+06	1.2E+02	9.3E+05	1.5E+01	3.1E+08	5.2E+03	2.8E+07	4.7E+02	5.6E+08	9.2E+03	9.3E+05	1.5E+01	1.0E+06	1.7E+01
Pu-239	8.5E+06	1.1E+01	1.1E+06	1.4E+00	2.9E+08	3.7E+02	3.1E+07	4.0E+01	6.3E+08	8.0E+02	1.1E+06	1.4E+00	1.2E+06	1.5E+00
Pu-240	8.5E+06	2.0E+01	1.1E+06	2.5E+00	2.9E+08	6.7E+02	3.1E+07	7.2E+01	6.3E+08	1.4E+03	1.1E+06	2.5E+00	1.2E+06	2.7E+00
Am-241	1.1E+08	1.6E+03	1.0E+07	1.4E+02	1.3E+08	1.8E+03	2.0E+08	2.9E+03	5.9E+09	8.5E+04	1.0E+07	1.4E+02	1.0E+07	1.4E+02
Pu-241	1.9E+05	3.3E+01	2.4E+04	4.3E+00	1.6E+06	2.8E+02	6.3E+05	1.1E+02	1.4E+07	2.5E+03	2.4E+04	4.3E+00	2.5E+04	4.4E+00
Am-243	1.1E+08	1.8E+01	1.0E+07	1.6E+00	1.2E+08	1.9E+01	2.0E+08	3.2E+01	5.9E+09	9.4E+02	1.0E+07	1.6E+00	1.0E+07	1.6E+00
Cm-243	7.8E+07	5.8E+00	5.9E+06	4.4E-01	1.3E+08	9.9E+00	1.6E+08	1.2E+01	4.1E+09	3.0E+02	5.9E+06	4.4E-01	6.3E+06	4.7E-01
Cm-244	6.3E+07	6.2E+02	4.4E+06	4.4E+01	1.3E+08	1.3E+03	1.3E+08	1.3E+03	3.2E+09	3.2E+04	4.4E+06	4.4E+01	4.4E+06	4.4E+01
Total Sum	--	8.0E+03	--	5.8E+03	--	1.8E+04	--	1.1E+04	--	1.4E+05	--	1.2E+05	--	5.8E+03

Notes: [a] ICRP 1999 [applying a unit conversion factor of 3.7E12 (rem/Ci)/(Sv/Bq)]

[b] Equation 6: Table 11b (3) × DCF × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr (Assumption 4.3.7) × 1,000 mrem/rem

CDE = committed dose equivalent.

Table IV-2a. Subsurface Release Worker Organ Dose Calculation (FGR-11 Dose Factors)

Nuclide	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)
	Gonad	Gonad	Breast	Breast	Lung	Lung	R Marrow	R Marrow	Bone Surface	Bone Surface	Thyroid	Thyroid	Remainder	Remainder
	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem
Cs-137	3.2E+04	2.5E-04	2.9E+04	2.3E-04	3.3E+04	2.5E-04	3.1E+04	2.4E-04	2.9E+04	2.3E-04	2.9E+04	2.3E-04	3.4E+04	2.6E-04
Crud Co-60	1.8E+04	5.9E-05	6.8E+04	2.3E-04	1.3E+06	4.3E-03	6.4E+04	2.1E-04	5.0E+04	1.7E-04	6.0E+04	2.0E-04	1.3E+05	4.5E-04
Fuel Co-60	1.8E+04	1.6E-07	6.8E+04	6.1E-07	1.3E+06	1.1E-05	6.4E+04	5.7E-07	5.0E+04	4.5E-07	6.0E+04	5.3E-07	1.3E+05	1.2E-06
Ni-63	6.3E+03	4.5E-08	6.3E+03	4.5E-08	1.1E+04	8.2E-08	6.3E+03	4.5E-08	6.3E+03	4.5E-08	6.3E+03	4.5E-08	6.3E+03	4.5E-08
Sr-90	9.8E+03	7.6E-06	9.8E+03	7.6E-06	1.1E+07	8.2E-03	1.2E+06	9.6E-04	2.7E+06	2.1E-03	9.8E+03	7.6E-06	2.1E+04	1.6E-05
Pm-147	7.0E-02	2.4E-13	1.3E-01	4.5E-13	2.9E+05	9.7E-07	3.0E+04	1.0E-07	3.8E+05	1.3E-06	7.3E-02	2.5E-13	2.2E+04	7.4E-08
Sm-151	1.5E-01	9.0E-13	5.5E-01	3.3E-12	1.2E+04	7.3E-08	4.1E+04	2.4E-07	5.1E+05	3.1E-06	4.9E-02	2.9E-13	2.8E+04	1.7E-07
Eu-154	4.3E+04	8.3E-07	5.7E+04	1.1E-06	2.9E+05	5.6E-06	3.9E+05	7.5E-06	1.9E+06	3.7E-05	2.6E+04	5.1E-07	4.2E+05	8.0E-06
Pu-241	1.0E+06	7.2E-04	7.9E+01	5.6E-08	1.2E+07	8.3E-03	5.3E+06	3.7E-03	6.6E+07	4.6E-02	3.4E+01	2.4E-08	2.2E+06	1.6E-03
Pu-238	3.8E+07	2.5E-03	1.6E+03	1.1E-07	1.2E+09	7.7E-02	2.1E+08	1.4E-02	2.7E+09	1.8E-01	1.4E+03	9.3E-08	1.0E+08	6.6E-03
Pu-239	4.4E+07	2.2E-04	1.5E+03	7.4E-09	1.2E+09	6.0E-03	2.4E+08	1.2E-03	3.0E+09	1.5E-02	1.4E+03	7.0E-09	1.1E+08	5.6E-04
Pu-240	4.4E+07	4.0E-04	1.6E+03	1.5E-08	1.2E+09	1.1E-02	2.4E+08	2.2E-03	3.0E+09	2.8E-02	1.4E+03	1.3E-08	1.1E+08	1.0E-03
Am-241	1.2E+08	6.8E-03	9.9E+03	5.6E-07	6.8E+07	3.8E-03	6.4E+08	3.6E-02	8.0E+09	4.5E-01	5.9E+03	3.3E-07	2.9E+08	1.6E-02
Am-243	1.2E+08	7.6E-05	5.6E+04	3.5E-08	6.6E+07	4.1E-05	6.4E+08	4.0E-04	8.0E+09	5.0E-03	3.1E+04	1.9E-08	2.9E+08	1.8E-04
Cm-243	7.7E+07	2.2E-05	2.3E+04	6.8E-09	7.2E+07	2.1E-05	4.4E+08	1.3E-04	5.4E+09	1.6E-03	1.4E+04	4.2E-09	2.1E+08	6.3E-05
Cm-244	5.9E+07	2.3E-03	3.8E+03	1.5E-07	7.1E+07	2.8E-03	3.5E+08	1.3E-02	4.3E+09	1.7E-01	3.7E+03	1.4E-07	1.8E+08	6.9E-03
Air Activation														
N-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dust Activation														
N-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	6.6E+02	2.8E-06	6.0E+02	2.5E-06	4.6E+03	1.9E-05	7.9E+02	3.3E-06	9.5E+02	4.0E-06	5.7E+02	2.4E-06	8.7E+02	3.7E-06
Al-28	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Si-31	1.7E+01	1.0E-08	1.7E+01	1.0E-08	1.4E+03	8.5E-07	1.7E+01	1.0E-08	1.7E+01	1.0E-08	1.7E+01	1.0E-08	2.7E+02	1.6E-07
K-42	4.0E+02	3.6E-07	3.9E+02	3.6E-07	8.0E+03	7.2E-06	3.9E+02	3.6E-07	3.9E+02	3.6E-07	3.9E+02	3.5E-07	5.8E+02	5.3E-07
Fe-55	1.9E+03	1.8E-07	1.9E+03	1.8E-07	1.9E+03	1.8E-07	1.9E+03	1.8E-07	1.9E+03	1.8E-07	2.0E+03	1.9E-07	4.5E+03	4.2E-07
Total Sum	--	1.3E-02	--	4.7E-04	--	1.2E-01	--	7.3E-02	--	8.9E-01	--	4.4E-04	--	3.4E-02

Notes: (a) Eckerman et al. 1988, Table 2.1 [applying a unit conversion factor of 3.7×10^{12} (rem/Ci)/(Sv/Bq)]

(b) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): Table 15a (2) × DCF × 3.33×10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem.

CDE = committed dose equivalent.

Table IV-2b. Subsurface Release Worker Organ Dose Calculation (ICRP-68 Dose Factors)

Nuclide	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)	DCF (a)	CDE (b)
	Gonad	Gonad	Breast	Breast	Lung	Lung	R Marrow	R Marrow	Bone Surface	Bone Surface	Thyroid	Thyroid	Remainder	Remainder
	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem	rem/Ci	mrem
Cs-137	2.2E+04	1.7E-04	2.0E+04	1.6E-04	2.3E+04	1.8E-04	2.3E+04	1.8E-04	2.4E+04	1.9E-04	2.3E+04	1.8E-04	3.5E+04	2.7E-04
Crud Co-60	2.5E+03	8.4E-06	8.5E+04	2.8E-04	6.3E+05	2.1E-03	4.4E+04	1.5E-04	3.3E+04	1.1E-04	3.5E+04	1.2E-04	3.3E+04	1.1E-04
Fuel Co-60	2.5E+03	2.2E-08	8.5E+04	7.6E-07	6.3E+05	5.6E-06	4.4E+04	4.0E-07	3.3E+04	2.9E-07	3.5E+04	3.1E-07	3.3E+04	3.0E-07
Ni-63	6.3E+03	4.5E-08	6.3E+03	4.5E-08	1.0E+04	7.4E-08	6.3E+03	4.5E-08	6.3E+03	4.5E-08	6.3E+03	4.5E-08	1.4E+04	9.8E-08
Sr-90	1.2E+02	9.5E-08	1.2E+02	9.5E-08	4.5E+06	3.5E-03	3.0E+04	2.3E-05	6.7E+04	5.2E-05	1.2E+02	9.5E-08	3.3E+02	2.6E-07
Pm-147	1.4E+00	4.8E-12	1.4E+00	4.9E-12	6.7E+04	2.3E-07	2.1E+04	7.3E-08	2.7E+05	9.0E-07	1.4E+00	4.8E-12	1.0E+01	3.4E-11
Sm-151	4.8E-01	2.9E-12	5.9E-01	3.6E-12	1.0E+04	6.2E-08	3.0E+04	1.8E-07	3.7E+05	2.2E-06	5.2E-01	3.1E-12	3.0E+00	1.8E-11
Eu-154	1.1E+04	2.2E-07	4.1E+04	7.8E-07	3.5E+05	6.7E-06	3.2E+05	6.1E-06	1.4E+06	2.8E-05	2.6E+04	5.0E-07	4.4E+04	8.5E-07
Pu-241	1.9E+05	1.3E-04	2.4E+04	1.7E-05	1.6E+06	1.1E-03	6.3E+05	4.4E-04	1.4E+07	9.9E-03	2.4E+04	1.7E-05	2.5E+04	1.7E-05
Pu-238	7.4E+06	4.8E-04	9.3E+05	6.0E-05	3.1E+08	2.1E-02	2.8E+07	1.9E-03	5.6E+08	3.6E-02	9.3E+05	6.0E-05	1.0E+06	6.8E-05
Pu-239	8.5E+06	4.3E-05	1.1E+06	5.4E-06	2.9E+08	1.5E-03	3.1E+07	1.6E-04	6.3E+08	3.2E-03	1.1E+06	5.4E-06	1.2E+06	6.0E-06
Pu-240	8.5E+06	7.7E-05	1.1E+06	9.7E-06	2.9E+08	2.6E-03	3.1E+07	2.9E-04	6.3E+08	5.7E-03	1.1E+06	9.7E-06	1.2E+06	1.1E-05
Am-241	1.1E+08	6.5E-03	1.0E+07	5.6E-04	1.3E+08	7.1E-03	2.0E+08	1.1E-02	5.9E+09	3.3E-01	1.0E+07	5.6E-04	1.0E+07	5.6E-04
Am-243	1.1E+08	7.0E-05	1.0E+07	6.3E-06	1.2E+08	7.4E-05	2.0E+08	1.3E-04	5.9E+09	3.7E-03	1.0E+07	6.3E-06	1.0E+07	6.5E-06
Cm-243	7.8E+07	2.3E-05	5.9E+06	1.7E-06	1.3E+08	3.9E-05	1.6E+08	4.7E-05	4.1E+09	1.2E-03	5.9E+06	1.7E-06	6.3E+06	1.8E-06
Cm-244	6.3E+07	2.4E-03	4.4E+06	1.7E-04	1.3E+08	5.2E-03	1.3E+08	5.2E-03	3.2E+09	1.2E-01	4.4E+06	1.7E-04	4.4E+06	1.7E-04
Air Activation														
N-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dust Activation														
N-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-24	4.8E+02	2.0E-06	4.8E+02	2.0E-06	7.0E+02	3.0E-06	1.6E+01	6.7E-08	1.6E+01	6.7E-08	1.6E+01	6.7E-08	5.9E+02	2.5E-06
Al-28	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Si-31	1.9E+01	1.1E-08	1.9E+01	1.1E-08	1.2E+03	7.1E-07	1.9E+01	1.1E-08	1.9E+01	1.1E-08	1.9E+01	1.1E-08	1.7E+03	1.0E-06
K-42	3.7E+02	3.4E-07	3.7E+02	3.4E-07	5.2E+02	4.7E-07	4.1E+02	3.7E-07	4.1E+02	3.7E-07	4.1E+02	3.7E-07	3.7E+03	3.4E-06
Fe-55	9.6E+02	9.0E-08	9.6E+02	9.0E-08	9.6E+02	9.0E-08	1.2E+04	1.1E-06	6.7E+03	6.2E-07	9.6E+02	9.0E-08	1.4E+04	1.4E-06
Total Sum	--	9.9E-03	--	1.3E-03	--	4.4E-02	--	2.0E-02	--	5.2E-01	--	1.1E-03	--	1.2E-03

Notes: (a) ICRP 1999 [applying a unit conversion factor of 3.7E12 (rem/Ci)/(Sv/Bq)]

(b) Equation 6 (with T=2,000 hr/yr, Assumption 4.4.4): Table 15b (2) × DCF × 3.33 × 10^{-4} m^3/s × 3,600 s/hr × 2,000 hr/yr × 1,000 mrem/rem.

CDE = committed dose equivalent.

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BSC	Engineering Change Notice *Complete only applicable items.*	1. QA: QA 2. Page 1 of 1

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3. Document Identifier:	4. Rev.:	5. Title:	6. ECN:
000-HSC-WHS0-00200-000-00C	Rev C	Normal Operation Airborne Release Calculation	1

7. Reason for Change:

To include requested ICRP-68 dose factors for dose calculations and update references and associated parameters.

ENG.20050801.0007

8. Supersedes Change Document:	☒ Yes If, Yes, Change Doc.: 000-HSC-WHS0-00200-000-00B ☐ No

9. Change Impact:

Inputs Changed:	☒ Yes ☐ No	Results Impacted:	☐ Yes ☒ No
Assumptions Changed:	☐ Yes ☒ No	Design Impacted:	☐ Yes ☒ No

10. Description of Change: (Address any "Yes" answers)

Included requested ICRP-68 dose factors for dose calculations and updated airborne dispersion factors.

11. Originator: (Print/Sign/Date) YuChien Yuan	[signature]	6/15/2005
Checker: (Print/Sign/Date) John Wang	[signature]	6/15/2005
Approved: (Print/Sign/Date) Dave Darling	[signature]	6/16/05